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TRAINING DEVICE EFFECTIVENESS: FORMULATION AND EVALUATION OF A METHODOLOGY

William R. Bickley

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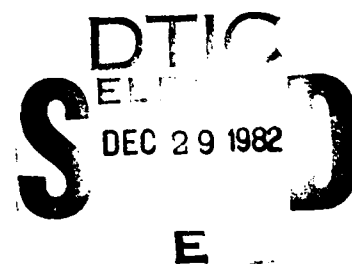
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RR 1291	2. GOVT ACCESSION NO. AD A122	3. RECIPIENT'S CATALOG NUMBER 777
4. TITLE (and Subtitle) TRAINING DEVICE EFFECTIVENESS: FORMULATION AND EVALUATION OF A METHODOLOGY		5. TYPE OF REPORT & PERIOD COVERED --
		6. PERFORMING ORG. REPORT NUMBER --
7. AUTHOR(s) William R. Bickley		8. CONTRACT OR GRANT NUMBER(s) --
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Research Institute Field Unit P.O. Box 476 Fort Rucker, AL 36362		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q263743A772
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Ave., Alexandria, VA 22333		12. REPORT DATE September 1980
		13. NUMBER OF PAGES 61
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) --		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE --

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Simulators	Helicopter training
Transfer of training	AH-1
Cost effectiveness	Flight training
Training effectiveness	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Assume that as amount of simulator training increases, the amount of aircraft training required to reach criterion decreases to some nonnegative minimum and that, at that point in antecedent simulator training, the rate at which subsequent required aircraft training decreases is a fixed proportion of the difference between present required aircraft training and the minimum required training achievable. Then the function relating $\underline{x}$, the amount of simulation training received, with $\underline{y}$, the subsequent training

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required in the aircraft to attain criterion, will be of the form $y = ae^{-bx} + c$. This formulation has tremendous utility in allowing the training analyst to calculate the most cost effective mixes of simulator and aircraft training. This approach was applied in the U.S. Army's acceptance tests of the AH-1 helicopter flight simulator. Nonlinear regression analyses of data collected on some 30 individual maneuvers indicate the methodology is viable. A straightforward methodology for incorporating these results into analysis of the combined cost and training effectiveness of the AH-1 simulator and similar training devices is presented.

TRAINING DEVICE EFFECTIVENESS: FORMULATION AND EVALUATION OF A METHODOLOGY

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The Organizations and Systems Research Laboratory of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) assists the Army as it seeks optimal utilization of its combat systems. ARI provides its assistance via two general avenues: by developing methods for training or selecting soldiers to interact wi and operate existing systems, and by participating in the development of new systems to assure that they are designed with the human operator in mind.

The work reported here involves a facet of development aimed at fielding a new training system for the AH-1 Cobra helicopter. As a part of Army Project 2Q263743A772, Aircrew Performance Enhancement in the Tactical Environment, ARI was an active participant in Operational Test II (OT II) of the AH-1 flight simulator. For OT II, ARI developed and implemented a transfer of training methodology designed to determine optimal trade-offs between differing amounts of relatively inexpensive simulator training and resultant relatively expensive training required in the AH-1 aircraft.

This paper presents the trade-off functions derived and a detailed description of the methodology employed. The methodology is suitable for evaluation of other simulators to be used in initial skill training.

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TRAINING DEVICE EFFECTIVENESS:
FORMULATION AND EVALUATION OF A METHODOLOGY

BRIEF
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Requirement:

In December 1978 the U.S. Army acquired a prototype AH-1 Cobra helicopter
flight simulator (AH1FS). The effectiveness of this machine as a training de-
vice and as an economy measure was not known at that time. A method was re-
quired that could yield quantified cost and training effectiveness indices.

Procedure:

Students receiving training on the AH-1 aircraft at the U.S. Army Aviation
Center (USAAVNC), Fort Rucker, Ala., spent varying amounts of time in the AH1FS
before advancing to training in the aircraft. The amount of required subsequent
training in the aircraft was recorded as a function of amount of AH1FS training
received. For each maneuver in the program of instruction (POI), trade-off
functions of AH1FS training versus subsequent required aircraft training were
derived.

Findings:

The AH1FS was found to be an effective training device in the sense that
subsequent to AH1FS training, less training was required in the aircraft. The
trade-off function parameters were quantified, and a method for maximizing the
cost and training effectiveness of the simulator was developed.

Utilization of Findings:

Training effectiveness results were used in USAAVNC's integration of the
AH1FS into the AH-1 POI. The cost-effectiveness and methodology and results
served as the primary input for the cost and training effectiveness analysis of
the AH1FS conducted by the U.S. Army Training and Doctrine Command.

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INTRODUCTION

Implicit in the acquisition of any simulation training system is the assumption that training objectives are more economically attained through a mix of simulation and hands-on training than through hands-on training alone. This was the concept guiding the U.S. Army in 1967 when the basic requirements and projects for a Synthetic Flight Training System (SFTS) were first elaborated. Faced on the one hand by rapidly increasing training and operating costs and encouraged on the other by advances being made in training simulator technology, the Army embarked on a long-range SFTS development program, developing first the UH-1 Iroquois (Huey) instrument flight simulator and then the CH-47 Chinook visual flight simulator. The latest addition to the SFTS program is the AH-1 Cobra visual flight and weapons system simulator (AH1FS). The first prototype AH1FS was accepted for Army operational and developmental testing in December 1978.

Overall summary reports of operational test results (Bridgers, Bickley, & Maxwell, 1980) and developmental test results (Millard, Casto, & Blackwell, 1979) appear elsewhere. This paper reports in detail the operational evaluation of the AH1FS as a training medium for transitioning rated rotary wing aviators to the AH-1 aircraft. The report has three general sections. The first describes the derivation of a novel methodology for evaluating simulators used in initial or transition training; the second presents the results of applying this methodology in testing the AH1FS; and the third describes how the data obtained can be used in the cost and training effectiveness analysis of a simulator.

METHODOLOGY

Training Effectiveness

As indicated above, the motive behind training simulator development is economy in training. The economy achieved is, of course, determined by the cost and the effectiveness of a unit of simulator training relative to the cost and effectiveness of a unit (in the present case) of aircraft training. With past simulators, the cost differential between simulator and aircraft training has been so great that a marginally effective simulator might be used to realize overall training savings. However, as simulators have grown more complex and expensive to operate, the differential has shrunk to the point that precise quantitative determination of training effectiveness is becoming a major step in U.S. Army simulator testing and acceptance procedures.

Training effectiveness can be viewed and defined in many ways (see Murdock, 1957), but as Roscoe (1971) points out, traditional measures of effectiveness fail to consider costs associated with pretraining or simulator training. Roscoe has proposed the cumulative transfer effectiveness ratio (CTER) as a more useful alternative for the training psychologist. The CTER is defined as

$$CTER = (y_o - y_i) / x_i, \qquad (1)$$

where $\underline{x}_i$ is training received in a simulator, y_i is training required in the aircraft after $\underline{x}_i$ simulator training, and y_o i, training that would be required in the aircraft were no simulator available. The ratio compares training savings in the aircraft as a function of amount of simulator training: a CTER of .75 would indicate that for some $\underline{x}_i$ units of simulator training, each unit is equivalent to .75 unit of aircraft training. The CTER is of great use to the training psychologist as a measure of training effectiveness and was successfully employed in Holman's (1978) evaluation of the CH-47 flight simulator.

But, as Roscoe points out, the CTER is not a constant but is very much a decreasing function of the value of $\underline{x}_i$. In fact, it can be seen that

$$\lim_{\underline{x}_i \to \infty} \left[\frac{y_o - y_i}{\underline{x}_i} \right] = 0. \tag{2}$$

Thus, each empirically established CTER will be valid only for some arbitrarily small neighborhood around its particular $\underline{x}_i$.

From the training psychologist's point of view, an ideal measure of training effectiveness should convey the same information as does the CTER, but it should also allow computation of training effectiveness of all $\underline{x}_i$. This could be accomplished by regressing CTER on various experimental values of $\underline{x}$, but a simpler and more direct approach is to regress $\underline{y}$ on $\underline{x}$; that is, find a suitable prediction rule or function that can be used to relate the independent variable of $\underline{x}$ relatively inexpensive units of flight simulator training with the dependent variable of $\underline{y}$ relatively expensive units of aircraft training required to attain the training objective. Once this training effectiveness function relating units of simulator training with units of subsequently required aircraft training is determined, the training psychologist can apply the respective cost factors associated with the two training media to the function and minimize the resulting total cost function.

Derivation of Model

Now that the potential utility of such a concept of training effectiveness has been illustrated, how can the function relating $\underline{x}$ and $\underline{y}$ be characterized? In this section, a model relating simulator and aircraft training will be developed, both intuitively and theoretically, and evaluated against extant empirical data.

At the intuitive level, one would expect that the function being sought would exhibit several characteristics. At $\underline{x}$ = zero (no simulator training), $\underline{y}$ is equal to the CTER's y_o, the amount of aircraft training required when a simulator is not used. As $\underline{x}$ increases, $\underline{y}$ should decrease; that is, as the amount of simulator training increases, the amount of subsequent required aircraft training should decrease. However, the rate of decrease should not be constant; from the nature of the CTER, it is known that the pay-back from investing more units of training in the simulator becomes less and less. That is, although

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the rate of change of y with increasing x is negative, it approaches zero, resulting in some asymptotic minimum nonnegative value of y that will be denoted by c. The value of c represents the amount of aircraft training that must be done to attain the training objective regardless of the amount of simulator training administered. For the training effectiveness model, c is conceptually representative of task elements that cannot be trained by simulation but must be learned in the aircraft. For those cases in which all task elements can be trained in the simulator, c would be equal to zero. An intuitive graph of the function is shown in Figure 1.
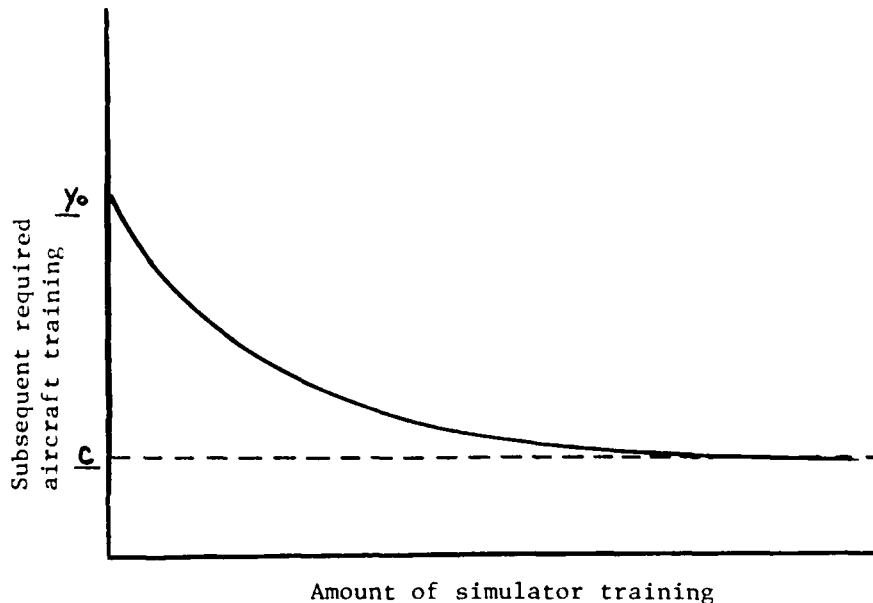
Figure 1. Hypothetical function relating amount of simulator training received with amount of subsequent required aircraft training.

Consider y as it ranges between a maximum at y_o and a minimum of $y = c$.

Just as c can be conceptualized as representative of the elements that must be learned in the aircraft, the quantity $y_o - c$ can be considered as representative of the potential aircraft savings that can be realized by using the simulator. Assume that, as x increases, the rate at which y decreases (and savings accrue) is a constant proportion of $y - c$. This assumption can be represented mathematically as the linear differential equation

$$\frac{d(y - c)}{dx} = -b(y - c), \tag{3}$$

where $\underline{b}$ is the proportional constant. Substituting $\underline{g}$ for $\underline{y} - \underline{c}$, equation (2) becomes

$$\frac{d(\underline{g})}{d\underline{x}} = -\underline{b}(\underline{g}),$$

which has general solution

$$\underline{g} = \underline{ae}^{-\underline{bx}}, \tag{4}$$

where $\underline{a}$ is an arbitrary constant. Replacing $\underline{g}$ by $\underline{y} - \underline{c}$ in (4) yields

$$\underline{y} - \underline{c} = \underline{ae}^{-\underline{bx}}$$

$$\underline{y} = \underline{ae}^{-\underline{bx}} + \underline{c}. \tag{5}$$

Equation 5 is then a good theoretical candidate for the function the training psychologist seeks in relating simulator training with aircraft training.

Other than the study reported here, little quantitative data for evaluation of the model are to be found in the literature; most training effectiveness studies are oriented toward transfer of training proportions or toward CTERS and have not systematically varied $\underline{x}$, the amount of simulator training given. A notable exception occurs in a study by Povenmire and Roscoe (1973). In evaluating a generic aircraft simulator, Povenmire and Roscoe gave general aviation students up to 11 hours of instruction in the simulator followed by training to criterion in the aircraft. These data are plotted in Figure 2. The curve in Figure 2 is a rough fit of equation 5 to their data. For this fit, the proportional constant $\underline{b}$ has an approximate magnitude of .397, which is well within its theoretically expected range.

Level of Analysis

To this point, no mention has been made of the specific level at which the proposed analysis is to be made. In the case of the Povenmire and Roscoe (1973) data, the analysis was made at the level of the entire curriculum: data were collected in terms of the total time students were trained in the simulator or in the aircraft. Thus, any measure of effectiveness derived is a measure of the training device as a whole. However, it may be that the device is more effective in one area of training than in another. The training analyst requires information as to the device's areas of greatest effectiveness so that training curricula may be developed that capitalize on the simulator's training strengths. One way this information can be obtained is by evaluating the simulator at the level of individual training maneuvers. In using this level of approach in the evaluation of the Army's CH-47 helicopter flight simulator (CH47FS), Holman (1978) found that although the CH47FS is effective overall (.82 average CTER), CTERs for individual maneuvers ranged from zero to 2.80.

In view of this finding, and since the AH1FS has incorporated most of the CH47FS's technical design features, it was decided to evaluate the AH1FS at the level of individual maneuvers. The general approach taken was to administer to
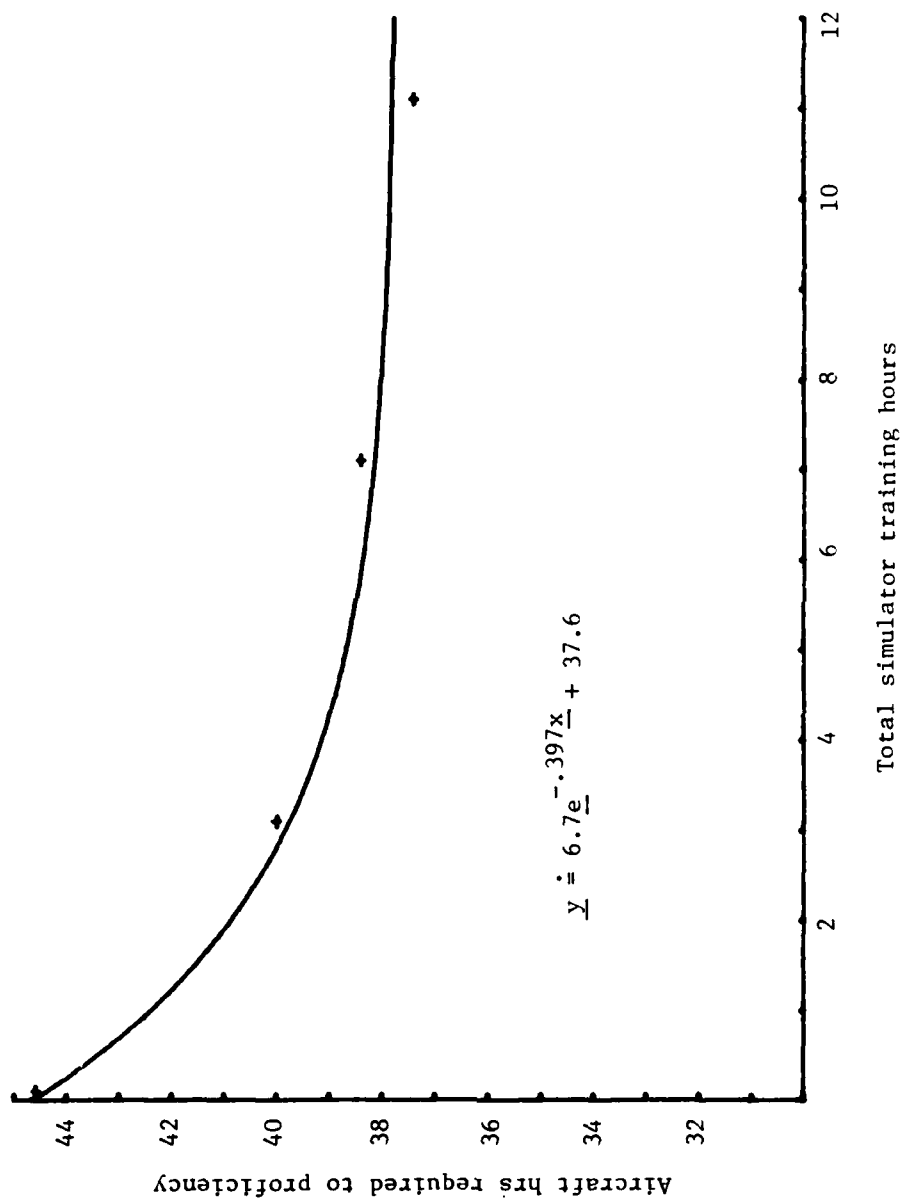
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Figure 2. Fit of model to Povenmire and Roscoe (1973) results.

$$\underline{\dot{y}} = 6.7e^{-.397\underline{x}} + 37.6$$

Total simulator training hours

Aircraft hrs required to proficiency

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regular flight students varying amounts of AH1FS training in each maneuver and then to observe the additional amounts of aircraft training required for them to attain proficiency.

PROCEDURE

Participants

Instructors. Instructor pilots (IPs) then assigned to the Attack/Aeroscout Branch of Hanchey Division of the Department of Flight Training of the Directorate of Training of the U.S. Army Aviation Center (USAAVNC) served as flight instructors. The IPs were all experienced aviators, qualified in the AH-1 aircraft, and graduates of the Attack/Aeroscout Branch's Methods of Instruction course.

Students. Participants were rated Army rotary wing aviators selected from regular USAAVNC AH-1 transition classes in residence from April to August 1979. Some participants received all their training in the AH-1 aircraft; others received AH1FS training followed by training in the aircraft.

Administrative constraints and scheduled daily AH1FS availability restricted the experimental sample size per class to eight for aircraft training only and to six for simulator plus aircraft training. Only commissioned officer students in the grade of captain or below and warrant officer students in the grade CW3 or below were considered. The remaining selection criterion was number of total flight hours: participants with the lowest number of total flight hours 1 · selected.

Apparatus

The AH1FS is a high-technology training device that simulates the AH-1 aircraft cockpit and instrumentation, aircraft motion and vibration, aircraft power plant and weapons noise, and out-the-window view. It is designed to afford training in visual contact flight, instrument flight, and weapons delivery techniques. A detailed description of the device is found in Millard et al. (1979); a more general description for the purposes of this report appears below.

As shown in Figure 3, the AH1FS has three general subsystems: the training platforms, the computer interface, and the camera model boards. The two training platforms correspond to the pilot's and the copilot/gunner's two cockpits in the AH-1 aircraft. Within a platform, the trainee's station is within the simulated cockpit, and the instructor's station is to the trainee's right rear. All aircraft controls and instruments are simulated for the trainee. At the instructor's station are the means for complete control of the training environment. The instructor has available three major training features: prerecorded maneuver demonstrations, problem "freeze," and training "play-back." The IP cannot easily manipulate the simulated cockpit controls but can invoke from the computer any of a number of recorded maneuvers to be demonstrated to the trainee. Also, at any point the instructor may freeze all training parameters in time and space, point out or discuss some matter of interest to the student, and then continue simulator training in real time. The play-back
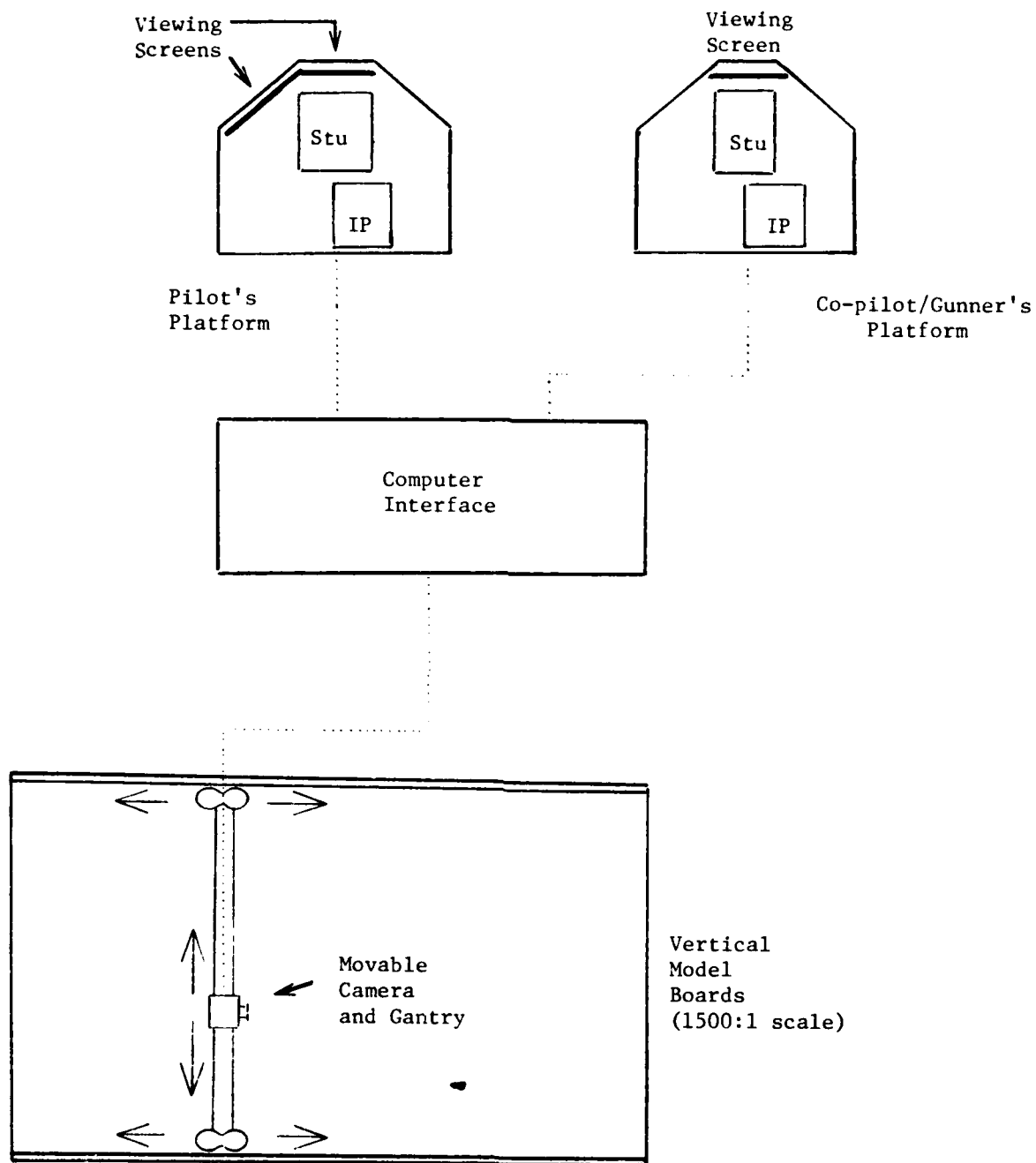
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Figure 3. General schematic of AH1FS.

feature allows the instructor to let a student review 1 to 5 minutes of the immediately preceding performance as recorded by the computer. Under normal training conditions, there is no need for instructors to interact with any personnel outside the training platforms.

The computer interface serves to translate the trainee's and the instructor's inputs into changes in the training environment. Trainee control inputs are translated into corresponding instrument and audio feedback, simulation motion of the training platform, and changes in the simulation visual scene. Instructor inputs are translated into training situation initial setups, replays of previous training, changes in simulation environmental variables, initiation of simulated aircraft malfunctions, and so forth.

The camera model boards are 1500:1 scale models of generic countryside, including gunnery ranges and a helicopter stagefield. Control inputs from the trainee platforms are translated by the computer interface into movement commands to a periscope positioned over the model board. The dynamic periscopic view is transmitted via a closed-circuit color television system to viewing screens at the simulated cockpit windows. The pilot's cockpit field of view (FOV) extends 18° above and below the horizontal and from 24° to the right of center to 77° to the left of center, for an effective 36° by 101° FOV. The gunner's cockpit FOV is 36° vertical by 48° horizontal centered straight ahead. The trainees are presented a virtual color image with a static visual resolution of approximately 10 arc minutes.

Preliminary Activities

Instructor Training. Before the study began, three experienced IPs, selected by the Scout/Attack Branch, received a 5-day instructor-operator course conducted by the simulator manufacturer. Primary topics were simulator operating procedures and simulator-specific instructional strategies. At the end of training, all three were judged as qualified AH1FS instructor-operators by both the manufacturer and the Army simulator test-acceptance pilot assigned to the project.

Data Specifications. As indicated above, it was decided the level of analysis for the study would be that of the individual maneuver. Prior to the study's start, the suite of maneuvers then taught by the Scout/Attack Branch was identified. Following the general format developed by Holman (1978), a booklet allowing for collecting data on up to four daily repetitions of each maneuver was developed. (Table 3 lists the maneuvers evaluated.) Data collected on any one maneuver repetition included the number of training minutes spent in performing the repetition and a rating of the trainee's overall performance on the repetition. The scale used for the overall rating is shown in Table 1. A rating of 7 on this scale corresponds to a satisfactory performance level.

All Scout/Attack Branch AH-1 IPs were instructed in the use of the data collection booklet and rating scale. Before starting the test, each IP had satisfactorily demonstrated use of the booklet by recording data from one of his regular transition course students.

Table 1

Maneuver Rating Scale

Rating	Description
0	Demonstration by IP; no evaluation.
1	IP immediately had to take back control of aircraft.
2	Performance deteriorated until IP was finally obliged to take back control of aircraft.
3	Student required considerable verbal assistance.
4	Some parameters within course limits; verbal correction from IP required.
5	Some verbal assistance required; less than one-half of parameters within course limits.
6	Minimal verbal assistance; more than one-half parameters within course limits.
7	Few parameters outside course limits; student corrected performance without coaching; still lacks good contrc' touch.
8	All parameters within course limits; work needed on control touch.
9	Outstanding; no perceptible deviations from standards; SIP-level performance.

AH1FS Training Amount Determination. As indicated previously, the overall test methodology was to involve observing the amount of aircraft training required after various amounts of AH1FS training. Subsequent regression analysis of these data would require that the amounts of AH1FS training selected be independent of the trainees. Specifically, in such a regression analysis, participants cannot have been trained to some level of proficiency; having done so, in effect, would have allowed trainees to determine their own amounts of AH1FS training and thereby have violated the underlying assumption of independent assignment of training amounts. Thus it was determined that for each maneuver, each participant would receive one of three prespecified numbers of training repetitions in the AH1FS.

Figure 1 indicates that the magnitudes of the three values chosen can be critical to the analysis. If all three independent variable values chosen are too large, then the resulting dependent variable values will all lie in the asymptotic portion of the curve, and inferences about the descending portion of the curve may lack precision. On the other hand, if all three values chosen

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are too small, then the dependent variable values will all lie in the descending portion of the curve, and inferences about the magnitude of the asymptote may lack precision. It can be seen that, ideally, independent variable values for each maneuver should be chosen so that resultant dependent variable values fall both in the descending and in the asymptotic portions of the curve.

Since the AH1FS was a new piece of equipment with no quantitative training effectiveness history, estimation of each maneuver's ideal amounts of training had to be based on several outside considerations. First, Scout/Attack Branch IPs were asked to estimate the average number of AH-1 aircraft repetitions the average AH-1 transition course student requires to reach institutional proficiency in the aircraft. Also, for maneuvers common to both the AH-1 and CH-47, data collected in the CH-47 flight simulator evaluation (Holman, 1978) were examined. Then, based on these data, on their sizable experience as IPs, and on their perceived effectiveness of the AH1FS as a training device, the AH1FS IPs and the simulator project test pilot individually and then collectively estimated for each maneuver three amounts of AH1FS training that should capture both the descending and the asymptotic portions of the generic curve shown in Figure 1. The values decided upon are indicated along the abscissae of the individual maneuver plots presented in the results section below.

Method

Because of various operational considerations, it was decided that participants trained in the AH1FS would each receive training on every maneuver in the simulator; data for each maneuver for the condition "no AH1FS training" were to be collected from participants receiving all their training in the AH-1 aircraft. The normal AH-1 transition course as taught at USAAVNC had a maximum of 12 students and lasted 4 weeks, with a new class starting every 2 weeks. Participants to receive AH1FS training were selected from every other class; participants to receive aircraft training only were selected from each class as feasible.

AH1FS Training. Participants to receive simulator training were instructed to consider the device as a "pretrainer" to facilitate their subsequent training in the aircraft; they were told not to expect the device to train them to proficiency. They followed the same general daily training routine as their aircraft-trained counterparts. The standard daily routine allowed for two instructors each to train three students for $1\frac{1}{2}$ hours each. Except for the use of simulator-specific features such as free, play-back, and demonstration tapes, the AH1FS instructor pilots followed the same standard curriculum and sequence of training that was being used in the aircraft. The only major departure from the standard was in progression through the curriculum: whereas individual training progression was based on proficiency in the aircraft, in the AH1FS progression was based on completion of the prespecified numbers of training iterations of each maneuver. For each participant for each maneuver, the prespecified level of training to be received was assigned randomly under the constraint that overall equal numbers of participants received each of the three levels. After completion of AH1FS training, participants began training in the aircraft.

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Aircraft Training. The AH1FS-trained participants' first exposure to the AH-1 aircraft was a diagnostic checkride administered by a Standardization Instructor Pilot (SIP) from the USAAVNC Directorate of Evaluation/Standardization. Based on the results of this checkride, the participant's AH1FS instructor continued training him to proficiency in the AH-1 aircraft. When the instructor considered the student proficient in the aircraft, the student was given an end-of-course aircraft checkride by another IP and released from training. Those participants not receiving training in the AH1FS received normal instruction and training in the aircraft.

RESULTS

Subjects

Instructor Pilots. Of the three instructors originally trained to operate the AH1FS, one participated in the entire study, one was never assigned to the study, and the third was released approximately halfway through the study because of an unavoidable reassignment within the Scout/Attack Branch. Before the third instructor's departure, he trained a successor who, prior to instructing in the simulator, was certified as qualified by the project test-acceptance pilot.

During the study, the Scout/Attack Branch experienced unforeseen shortages of both personnel and aircraft. The effects upon the study were twofold: new IPs with no experience with the data collection booklet entered the training system, and many times students trained in the aircraft received aircraft instruction from more than one IP. As new IPs began carrying students, they were instructed in the use of the data collection booklet and began collecting data on their students. A new IP's first students' data were discarded. Also, any data on students receiving instruction from more than two IPs (not counting the checkride IPs) during the 4-week transition course were discarded from the analysis.

Students. A total of 21 students began training in the AH1FS. With the exception of one who was grounded for medical reasons unrelated to the test, all successfully completed AH-1 flight training. A total of 25 students entered the study to receive aircraft training only. Due to the above-mentioned problems with instructor availability, data from all but 14 of these students were discarded. Descriptive data of all 35 students is shown in Table 2.

Maneuvers

Missing Data. If in simulator training a participant received as many as two fewer or as many as two more training repetitions for a maneuver than had been assigned, the data for that maneuver were discarded. This condition generally arose because of abnormally low simulator availability or through oversight on the part of the simulator IPs. Also, for some maneuvers, some students trained in the aircraft alone were neither trained to criterion (as defined below) nor tested on that maneuver on the end-of-course checkride. Data in these cases were also discarded. Thus, in most of the results given below, data for a maneuver are based on a sample of fewer than 35.

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Table 2

Student General Characteristics

Characteristic	Low	Average	High
1. Age	21	27	32
2. Total rotary wing (RW) flight hours	160	594	2,500
3. Total RW flight hours in last 6 months	0	95	190
4. Years since graduation from RW flight school	0	2.3	9

Overtraining. It was discovered early in the study that although the AH-1 transition course was (within the limits of its 4-week duration) self-paced and proficiency-based, overtraining unavoidably occurred on some maneuvers. For example, since most training involving takeoffs and landings or autorotations involved flying a traffic pattern around the training stagefield, students in the aircraft routinely received considerable overtraining in flying traffic patterns. Thus, after consulting with all the instructors involved, it was decided that a student would, for purposes of the study, be considered to have attained proficiency on a maneuver in the aircraft after earning a rating of 7 for three consecutive training repetitions and, of course, after earning at least a 7 on the maneuver on the end-of-course checkride. All aircraft training subsequent to the three 7s criterion was considered overtraining and not included in the analysis below.

Presence of Trend. As a general indicant of degree of overall relationship between amount of AH1FS training and subsequent required AH-1 aircraft training, eta-squared was computed for the data for each maneuver. The values found, which for this sample of participants may be interpreted as the proportion of variance accounted for by knowledge of amount of AH1FS training, are entered in Table 3.

Regression Analysis. For each maneuver, the data described above were fit to the function $\underline{f}(\underline{x}) = \underline{a}e^{-\underline{b}\underline{x}} + \underline{c}$ using the SPSS subprogram NONLINEAR (Robinson, 1977). Marquardt's method was used to obtain parameter estimates; iteration ceased when the largest relative change among the three parameters became less than 1.5×10^{-8}.

Figures 4 through 34 show the results for 31 maneuvers. Each figure shows the observed mean amount of aircraft training required after various amounts of AH1FS training and the standard error of the mean. For each maneuver, the curve generated by its best-fit parameters is plotted through the data points, and an $\underline{F}$-ratio of goodness-of-fit (Lewis, 1960) is given.

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Table 3

Degree of Association Between AH1FS and AH-1 Training

	Maneuver	$\underline{N}$	$\underline{\eta}^2$
1.	Cockpit procedures	34	.82
2.	Takeoff to a hover	32	.56
3.	Hover flight	33	.59
4.	Landing from a hover	35	.71
5.	High-speed flight	33	.60
6.	Normal takeoff	33	.35
7.	Normal approach	33	.79
8.	Maximum power takeoff	29	.63
9.	Steep approach	30	.44
10.	Running landing	23	.64
11.	Traffic pattern	33	.64
12.	Hydraulics failure	27	.72
13.	Forced landing, power recovery	27	.53
14.	Autorotation to touch-down	31	.53
15.	Autorotation with turn	33	.29
16.	Autorotation, termination with power	19	.05
17.	Hovering autorotation	32	.49
18.	Left anti-torque failure	28	.61
19.	Right anti-torque failure	27	.53
20.	Low-level autorotation	28	.43
21.	Low-level, high-speed autorotation	26	.24
22.	Hover out of ground effect	25	.56
23.	Terrain flight takeoff	23	.48
24.	Terrain flight	26	.44
25.	Terrain flight approach	22	.36
26.	SCAS off operations	22	.09
27.	Weapons cockpit procedures	25	.49
28.	FFAR ballistic correction	27	.46
29.	FFAR firing	28	.49
30.	20mm ballistic correction	27	.74
31.	20mm firing	24	.65

$$\underline{Y} = 6.42e^{-1.88\underline{x}} + 2.66$$

$$\underline{F}_{(1,30)} = 3.71$$
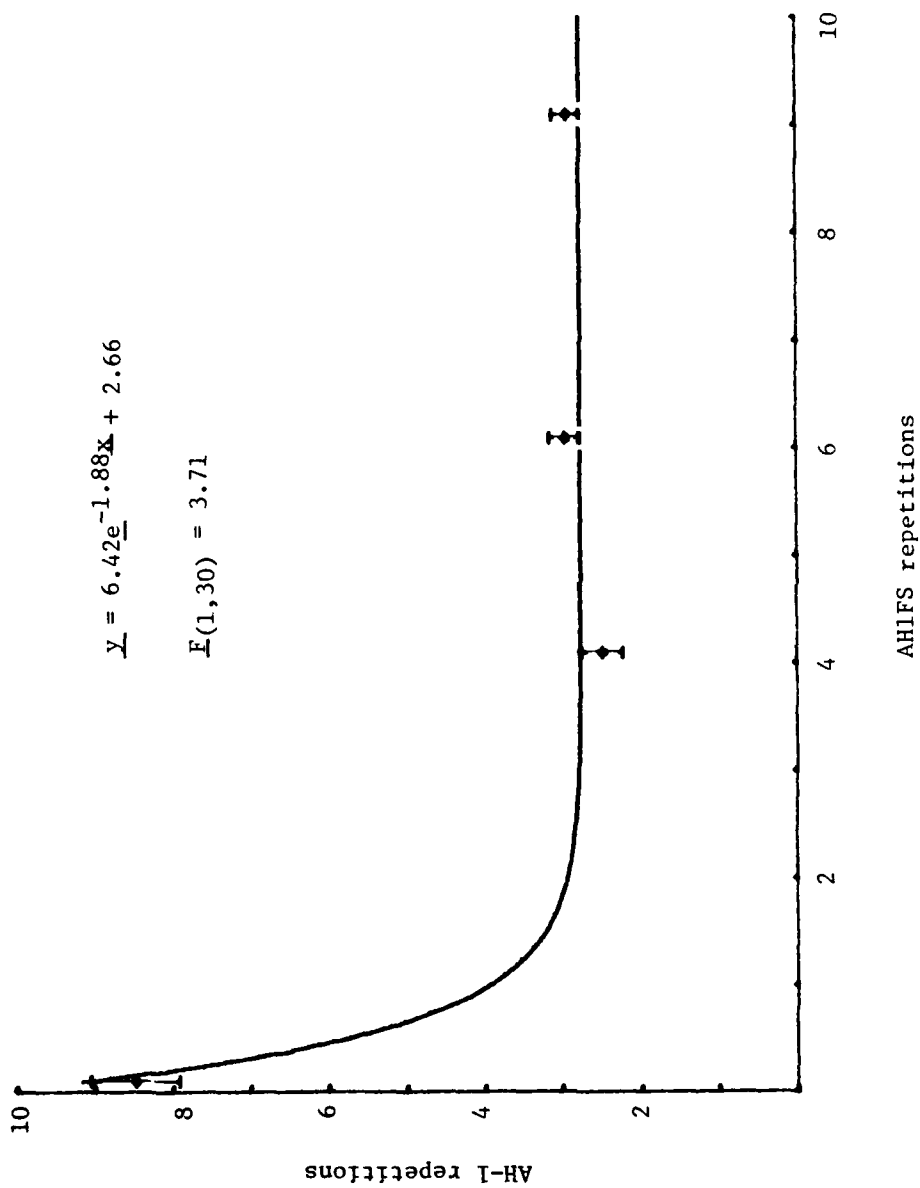
Figure 4. Cockpit procedures.
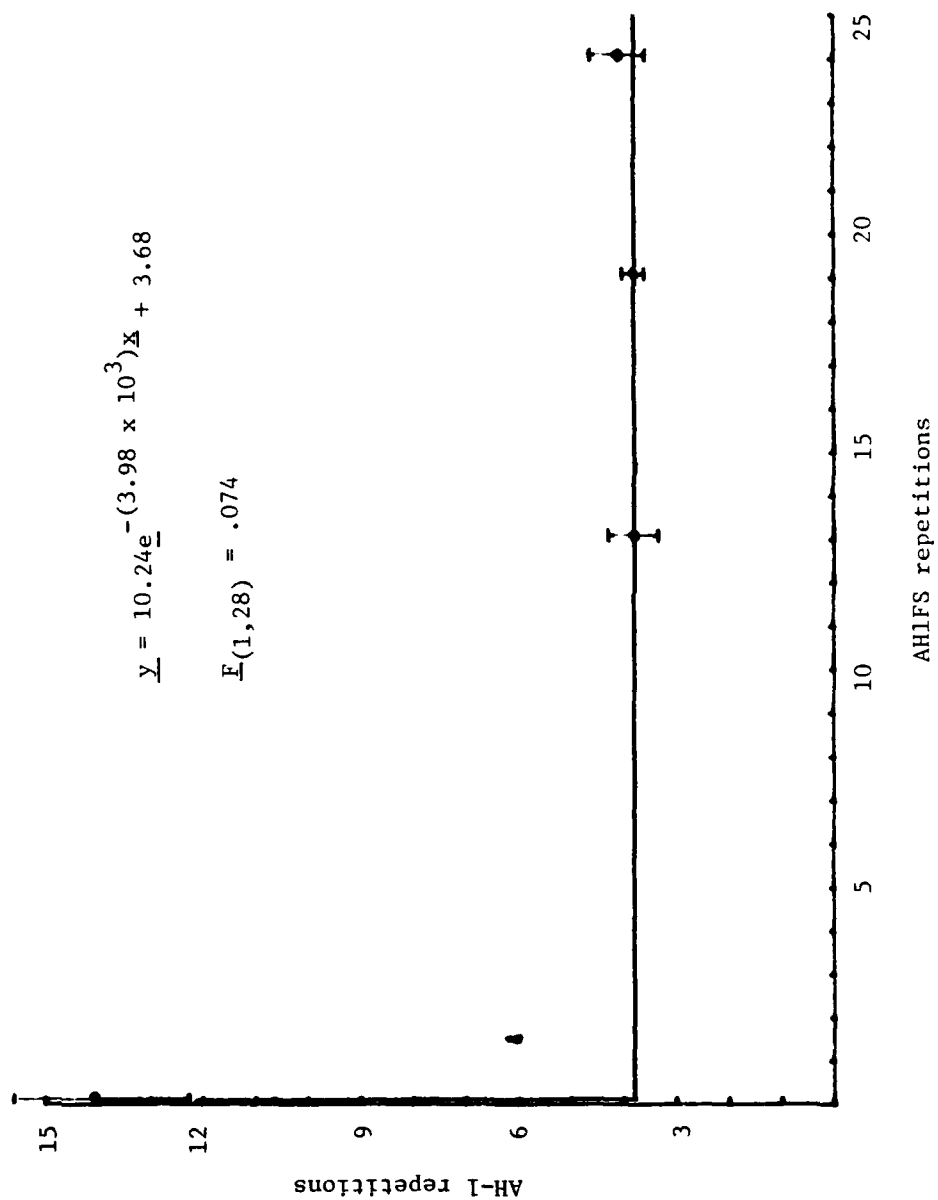
14

$$\underline{y} = 10.24\underline{e}^{-(3.98 \times 10^3)\underline{x}} + 3.68$$

$$\underline{F}_{(1,28)} = .074$$

AH1FS repetitions

AH-1 repetitions

Figure 5. Takeoff to a hover.

$$\underline{Y} = 11.87\underline{e}^{-.368x} + 3.35$$

$$\underline{F}_{(1,29)} = .033$$

AH1FS repetitions

AH-1 repetitions

Figure 6. Hover flight.

16

$$\underline{y} = 10.24\underline{e}^{-(3.98 \times 10^3)\underline{x}} + 3.68$$

$$\underline{F}_{(1,28)} = .074$$

Figure 5. Takeoff to a hover.

$$\underline{Y} = 10.23\underline{e}^{-.390\underline{x}} + 2.98$$

$$\underline{F}_{(1,31)} = .029$$

AH1FS repetitions

AH-1 repetitions
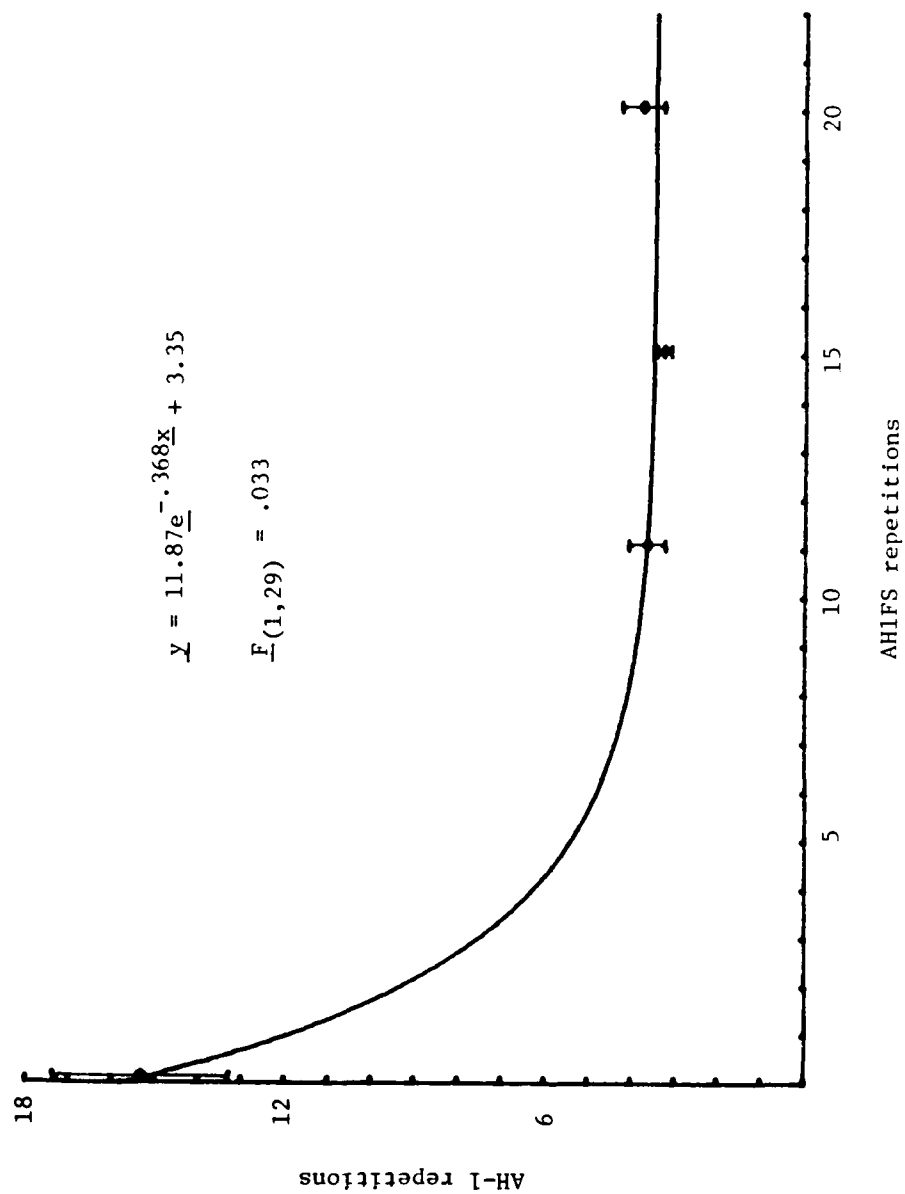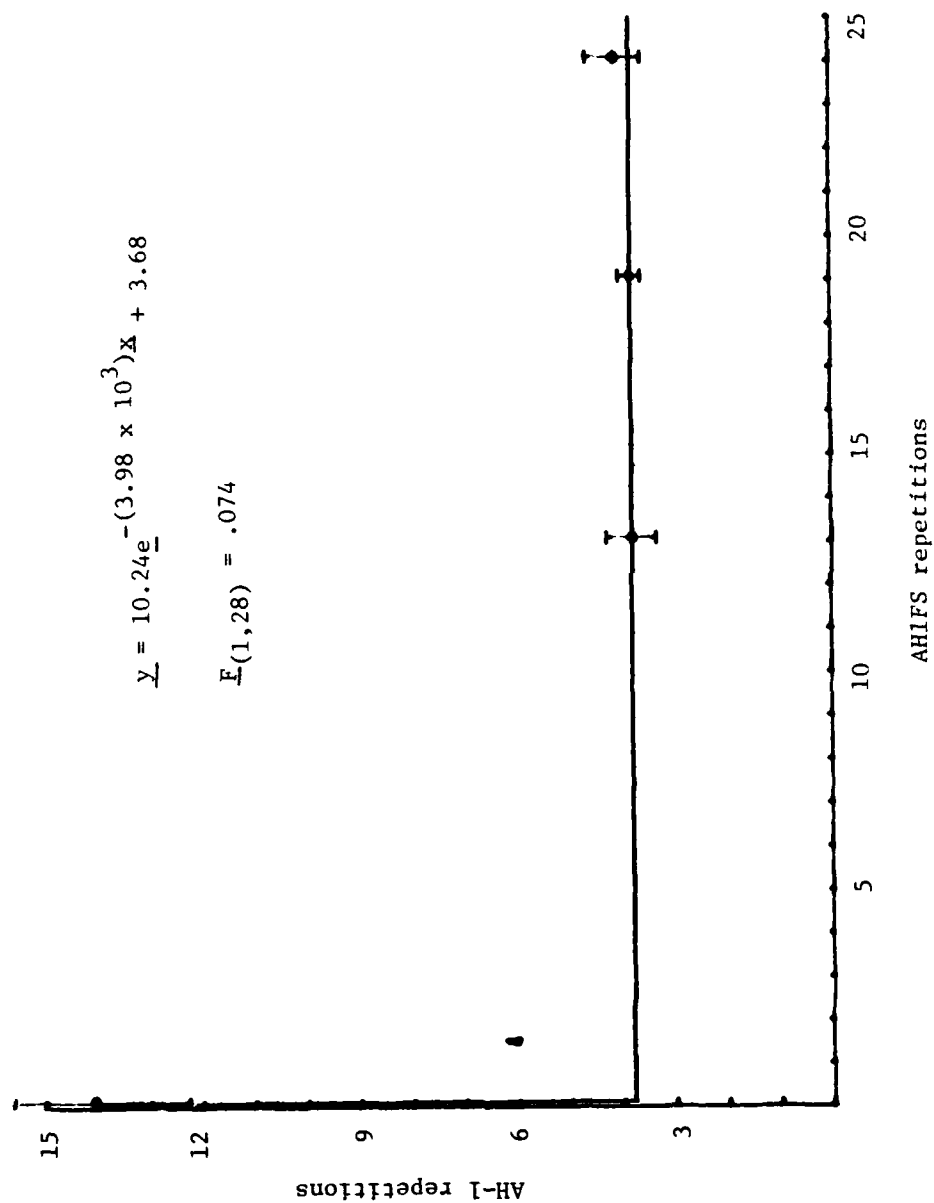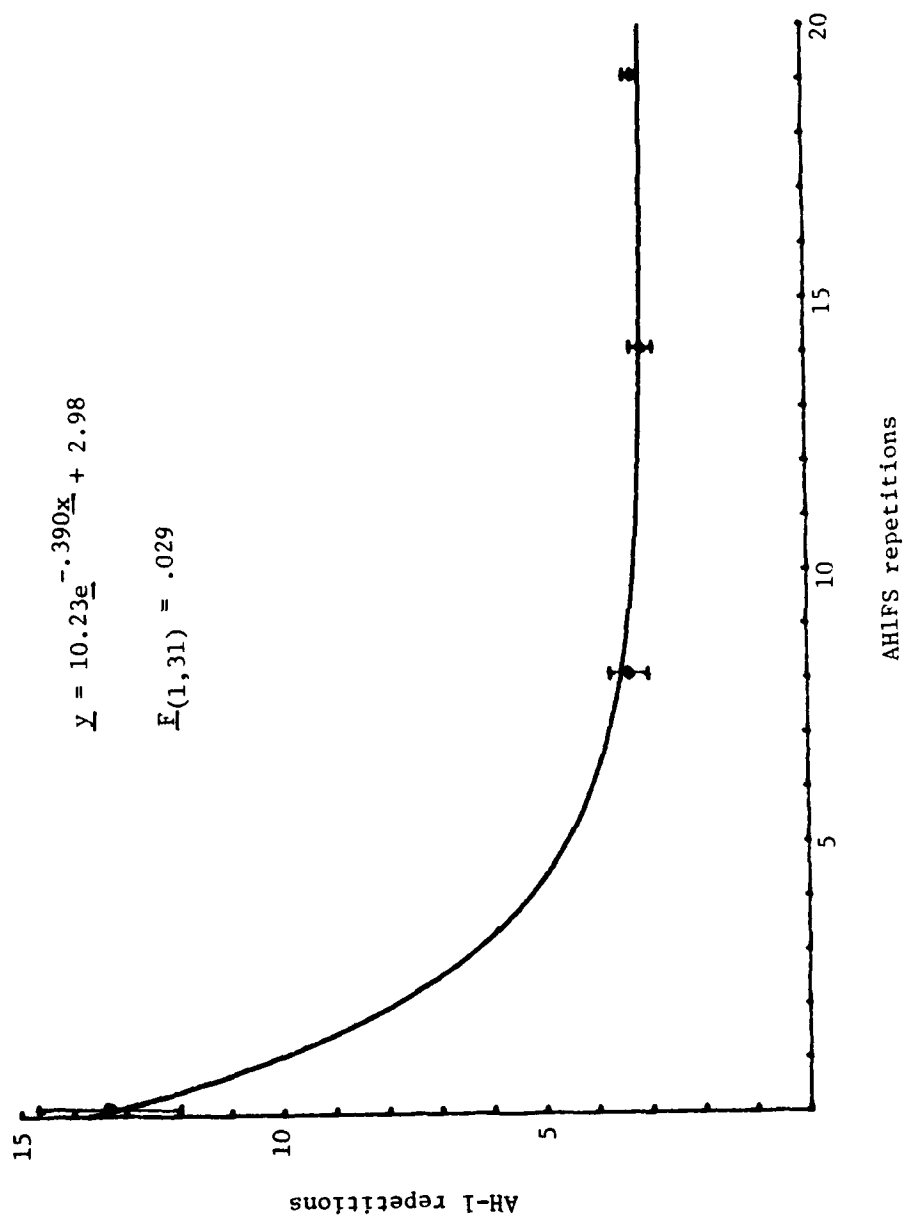
Figure 7. Landing from a hover.
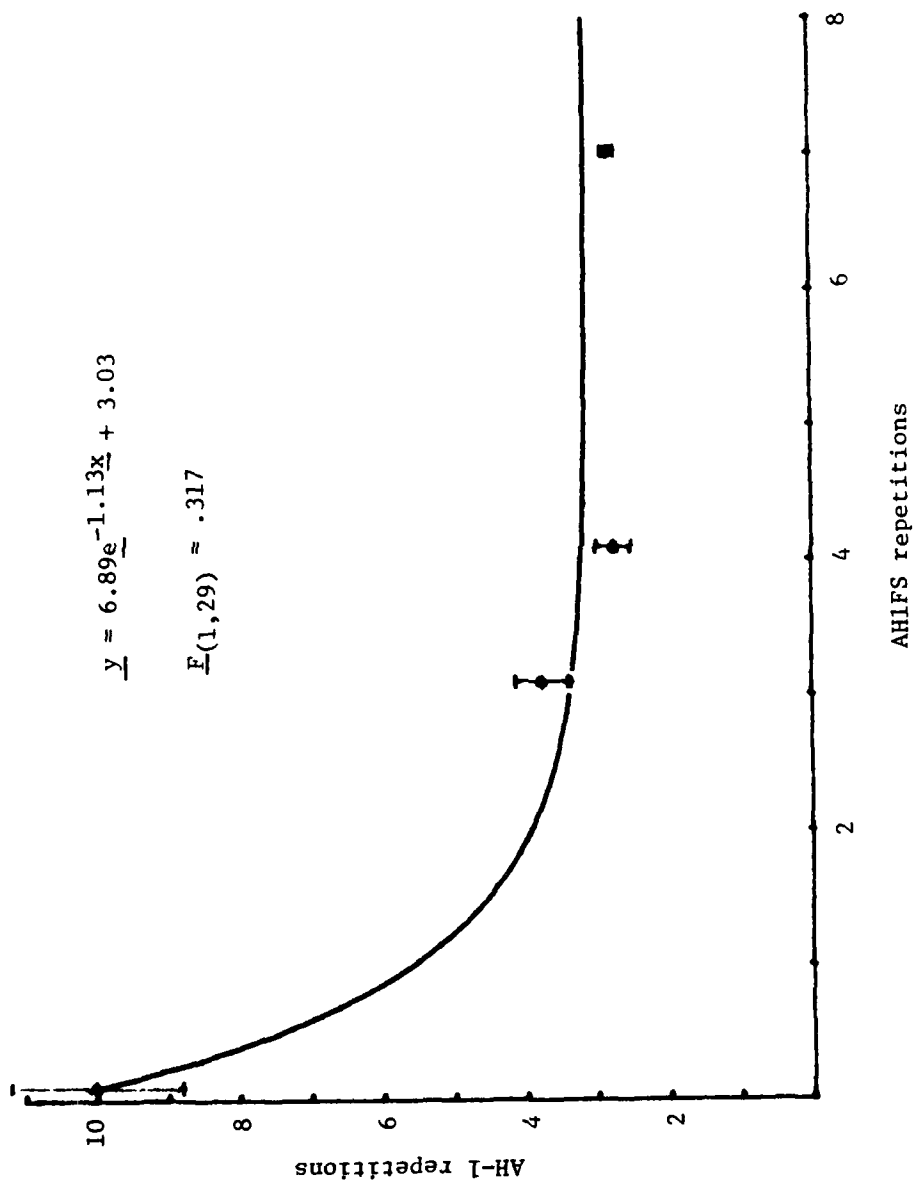
Figure 8. High-speed flight.

$$\underline{y} = 6.89\underline{e}^{-1.13\underline{x}} + 3.03$$

$$\underline{F}_{(1,29)} = .317$$

AH1FS repetitions

AH-1 repetitions

$$\underline{y} = 13.86\underline{e}^{-.161\underline{x}} + 2.57$$

$$\underline{F}_{(1,29)} = .198$$

AH1FS repetitions

AH-1 repetitions

Figure 9. Normal takeoff.

$$\underline{y} = 9.96\underline{e}^{-.131\underline{x}} + 2.02$$

$$\underline{F}(1,29) = .696$$

AH1FS repetitions

AH-1 repetitions
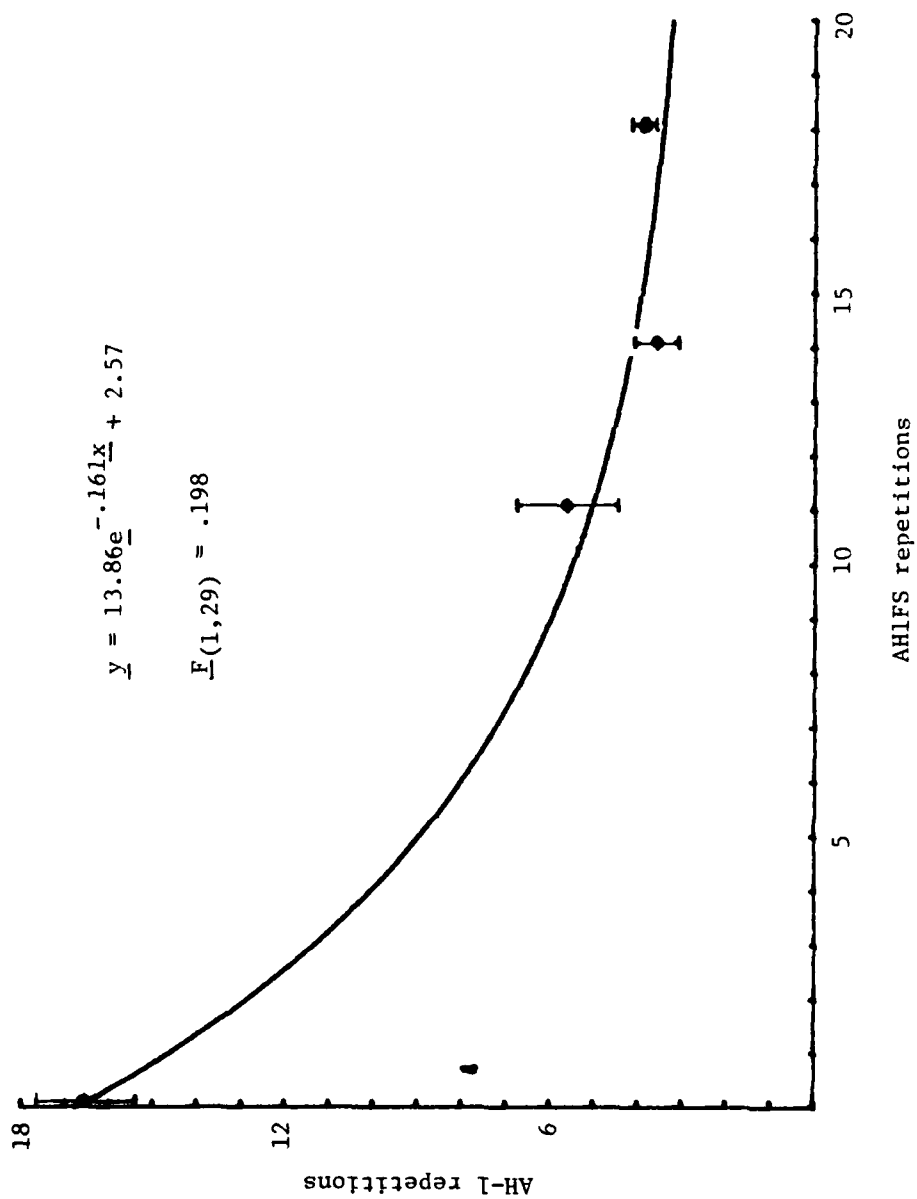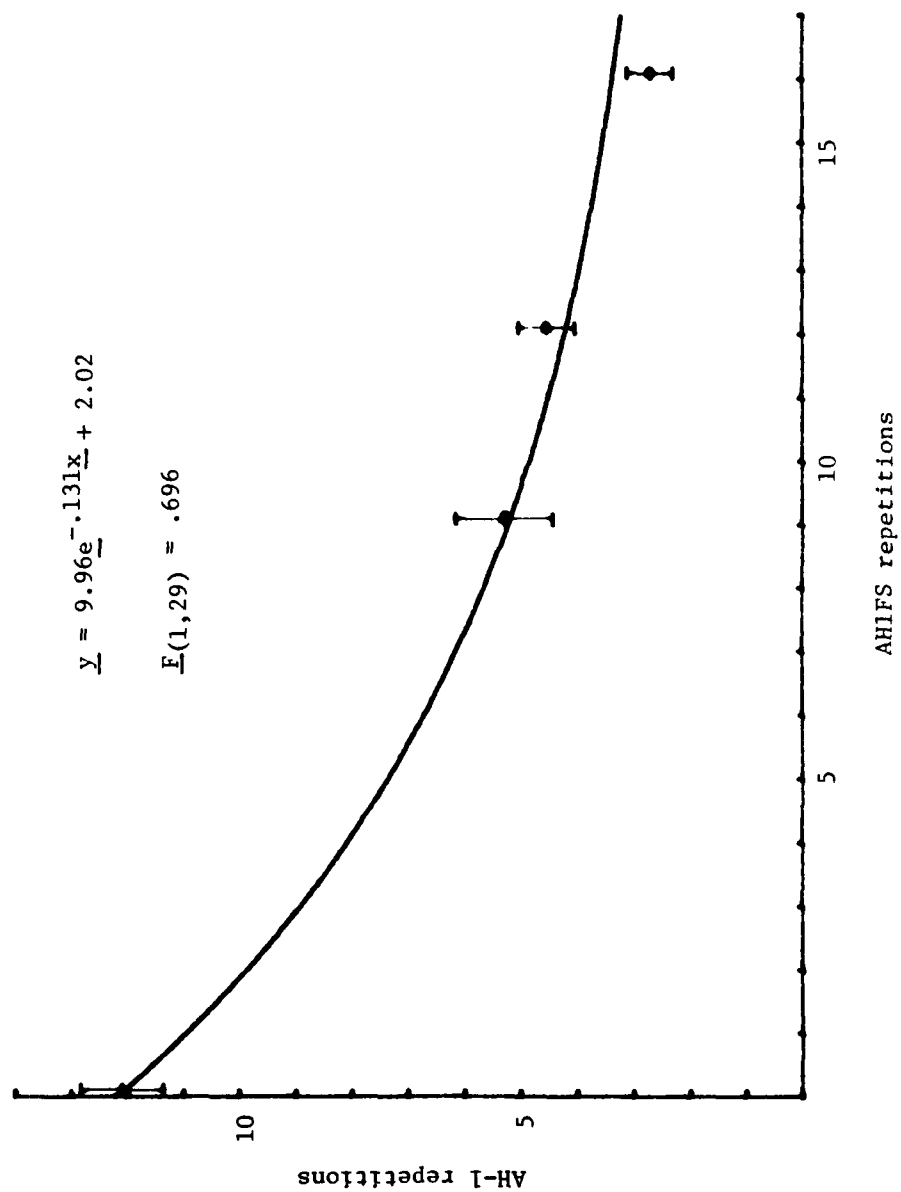
Figure 10. Normal approach.
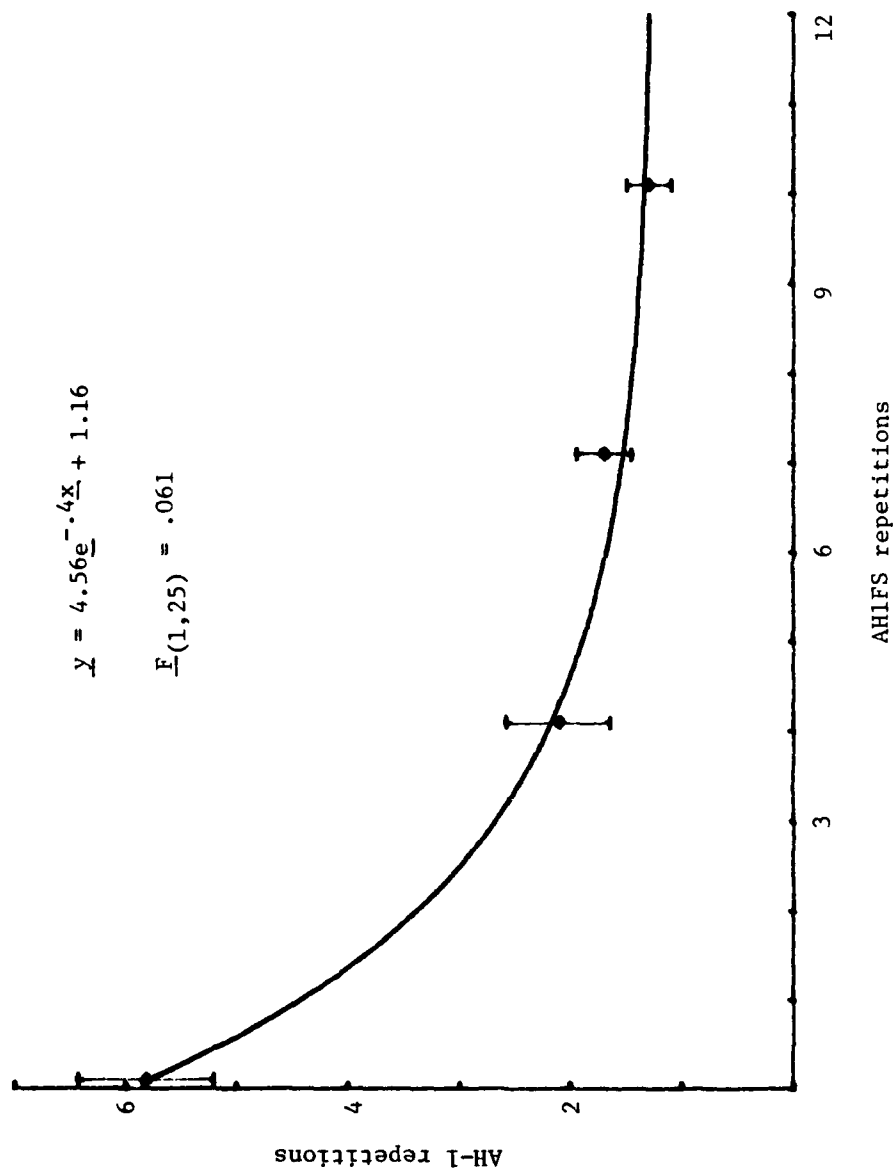
Figure 11. *Maximum power takeoff.*

21

$$\underline{y} = 2.88\underline{e}^{-.72\underline{x}} + 1.58$$

$$\underline{F}_{(1,26)} = 1.243$$

AH1FS repetitions

AH-1 repetitions
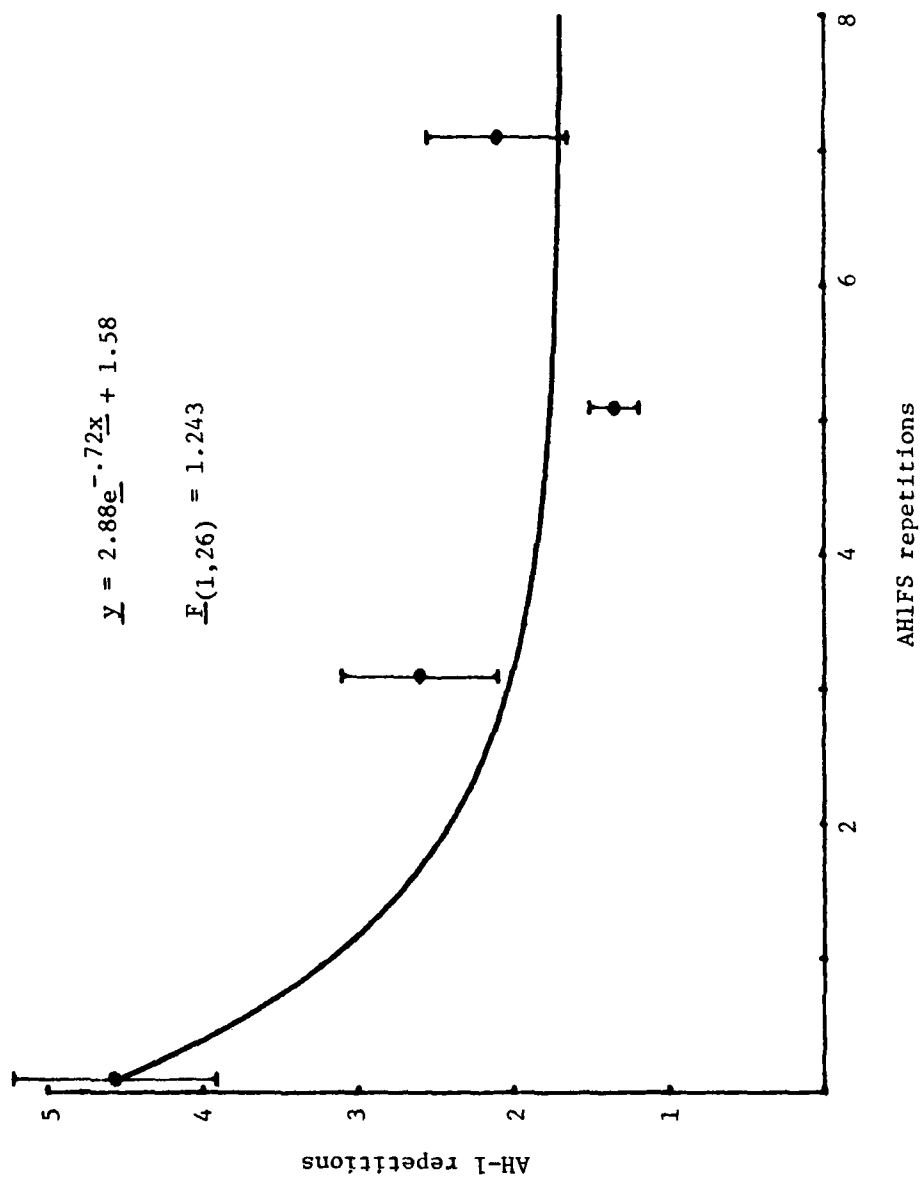
Figure 12. Steep approach.

22

$$\underline{y} = 1.95\underline{e}^{-.436\underline{x}} + .78$$

$$\underline{F}_{(1,19)} = 1.180$$

AH1FS repetitions

AH-1 repetitions
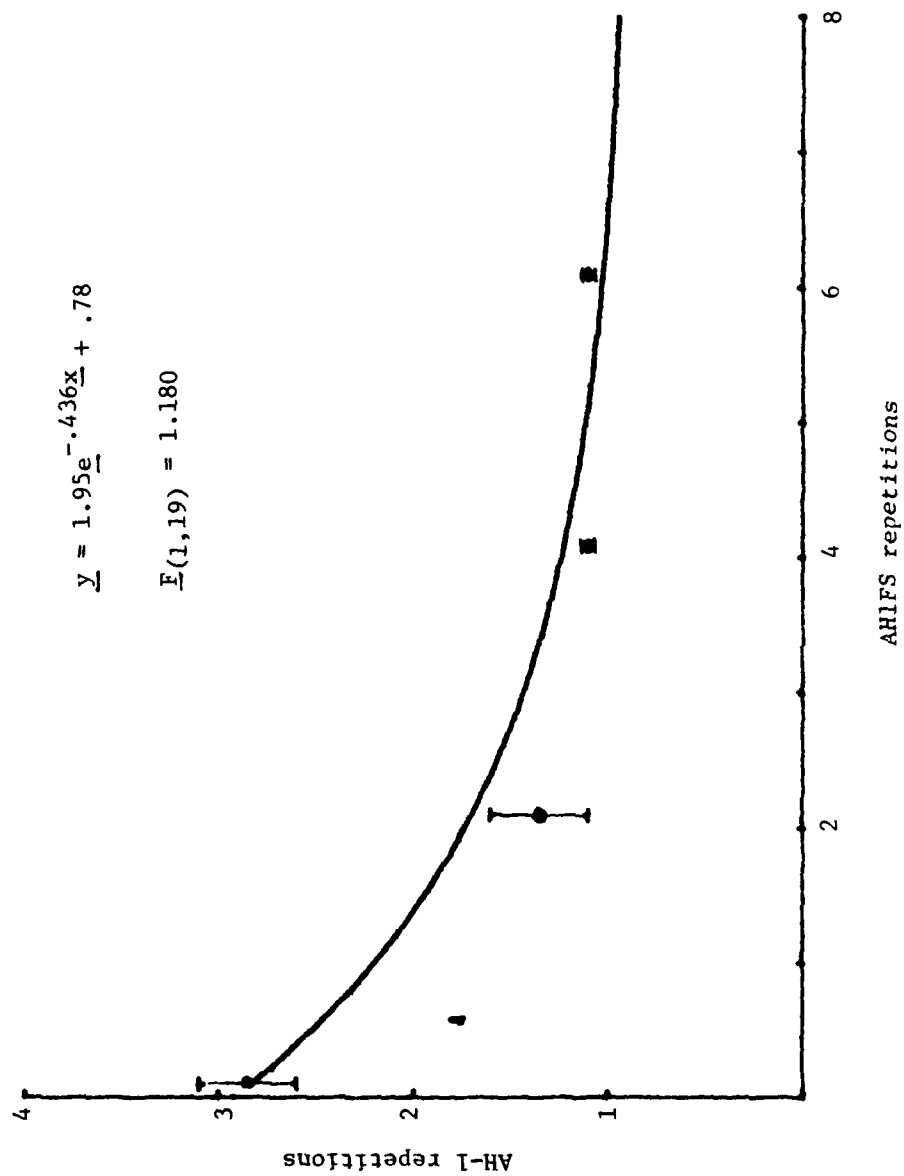
Figure 13. Running landing.

$$\underline{y} = 16.36\underline{e}^{-.608\underline{x}} + 4.57$$

$$\underline{F}_{(1,29)} = .024$$

AH1FS repetitions

AH-1 repetitions
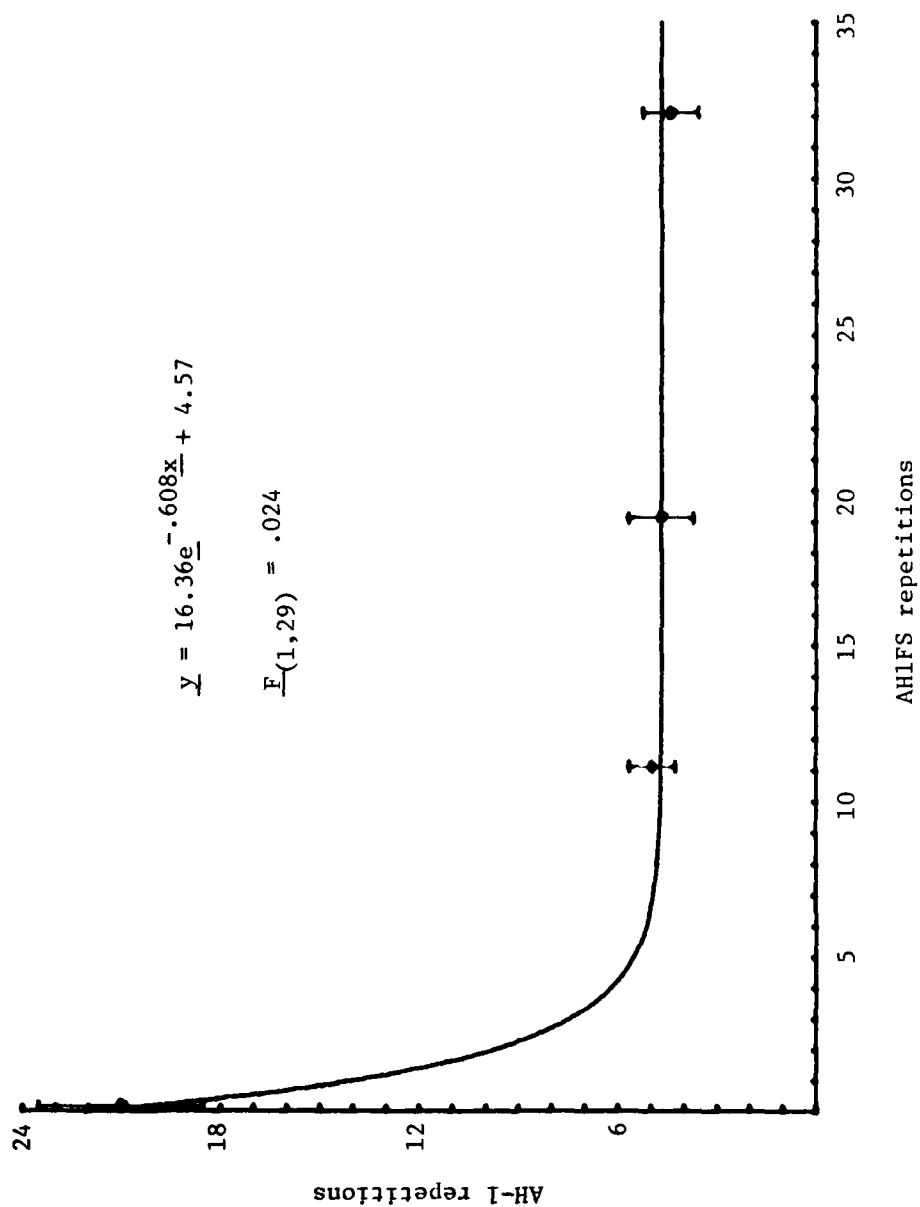
Figure 14. Traffic pattern.

$\underline{y} = 8.18\underline{e}^{-.179} + 1.54$

$\underline{F}_{(1,23)} = .036$

AH1FS repetitions

AH-1 repetitions
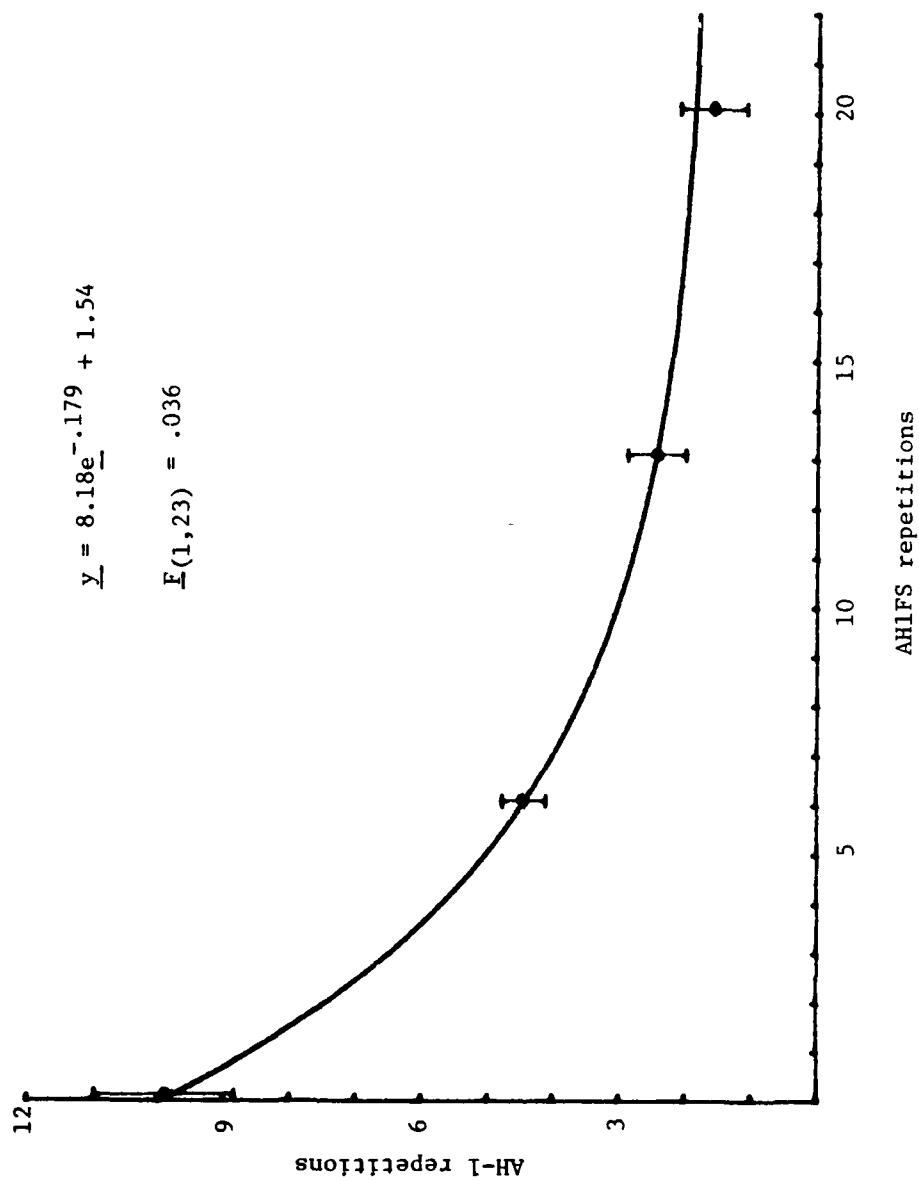
Figure 15. Hydraulics failure.

$$\underline{y} = 8.35\underline{e}^{-(1.5 \times 10^6)\underline{x}} + 3.15$$

$$\underline{F}(1,23) = .038$$

AH1FS repetitions

AH-1 repetitions
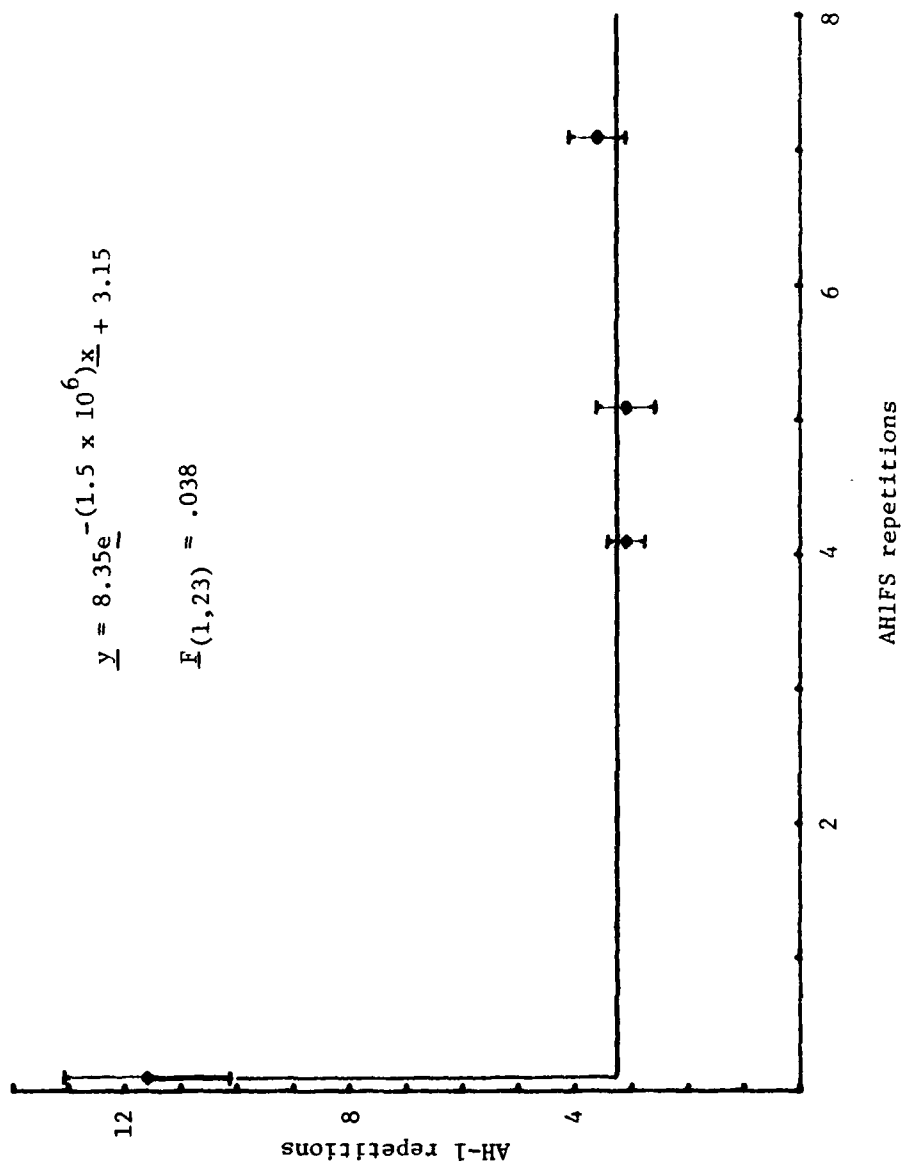
Figure 16. Forced landing, power recovery. (Axes offset to aid legibility.)

$$\underline{y} = 8.34e^{-(5.1 \times 10^{35})\underline{x}} + 4.44$$

$$\underline{F}(1,29) = .099$$

Figure 17. Autorotation to touch-down.

27
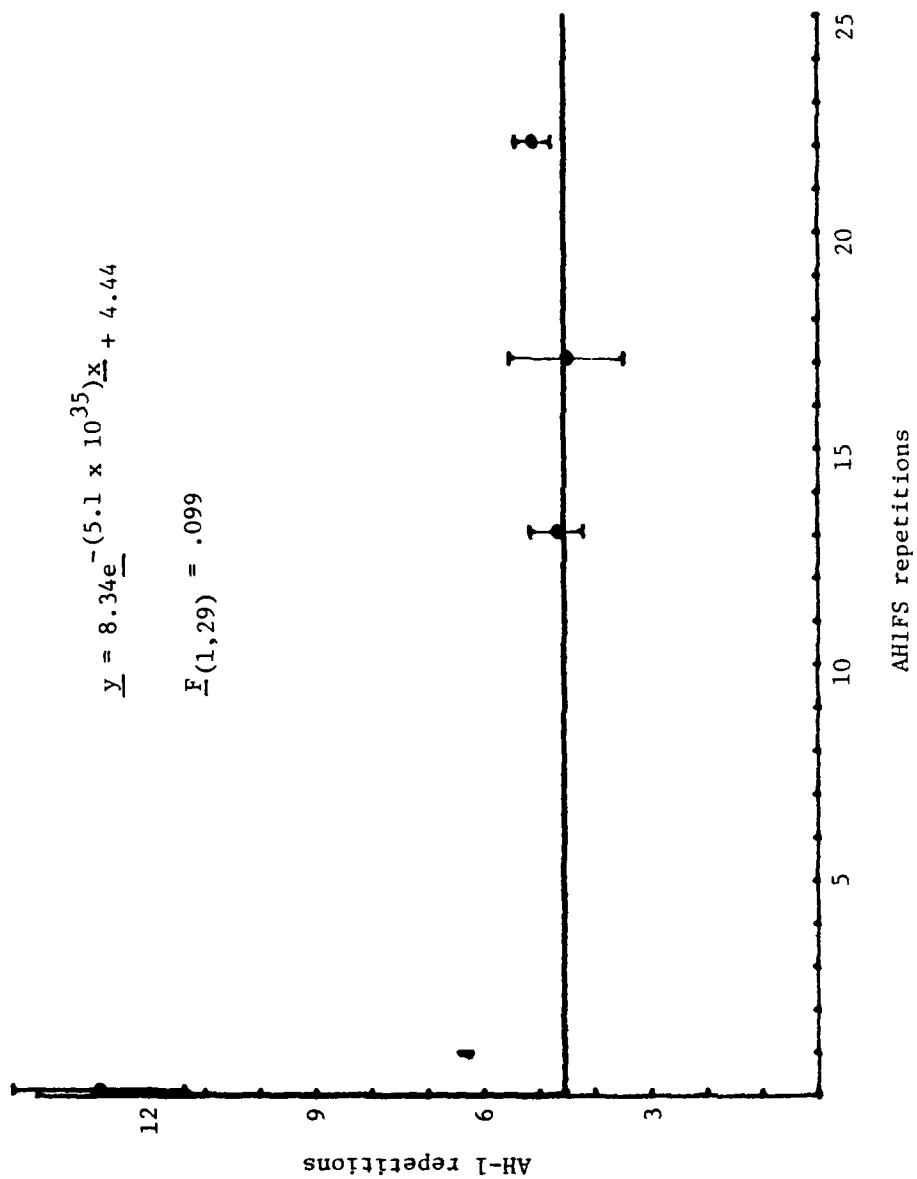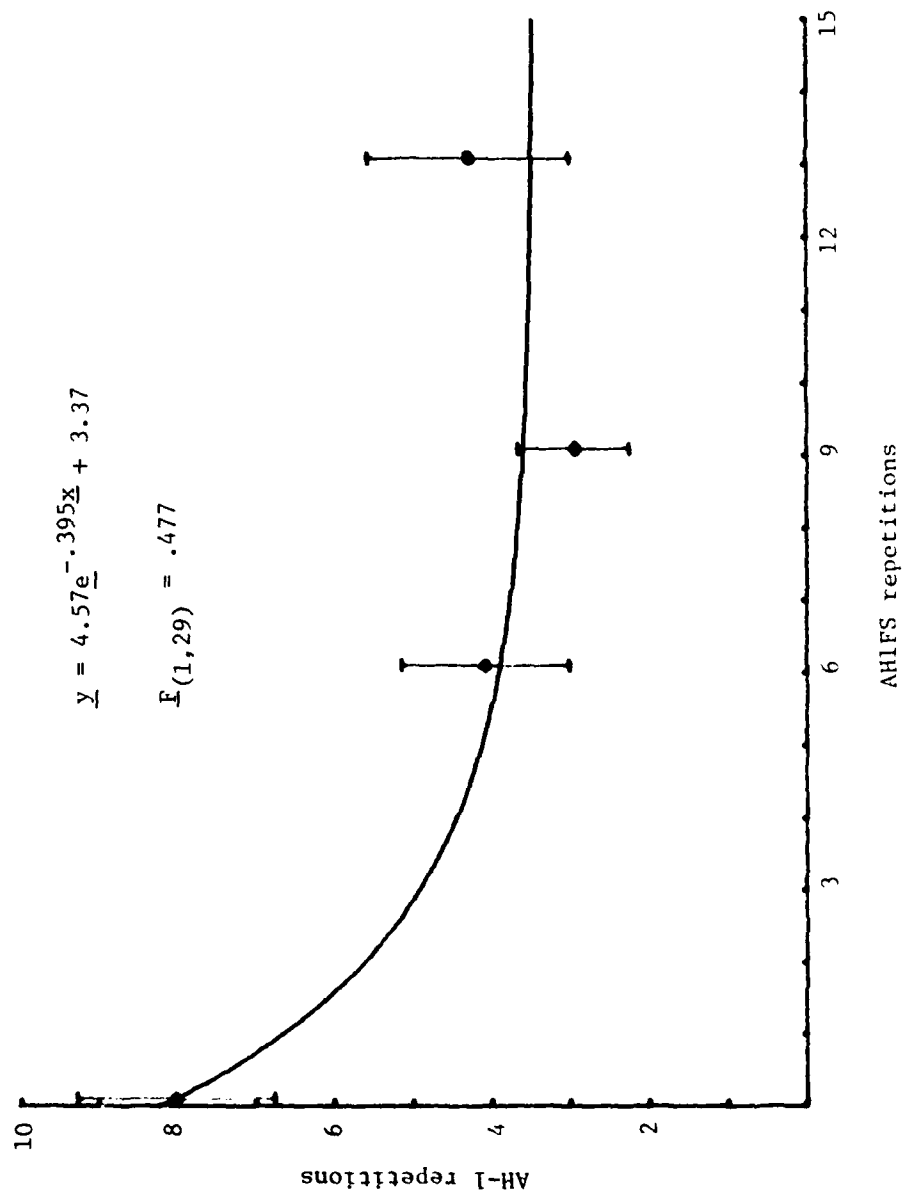
Figure 18. Autorotation with turn.

$$\underline{y} = 4.57\underline{e}^{-.395\underline{x}} + 3.37$$

$$\underline{F}_{(1,29)} = .477$$

AH1FS repetitions

AH-1 repetitions

28
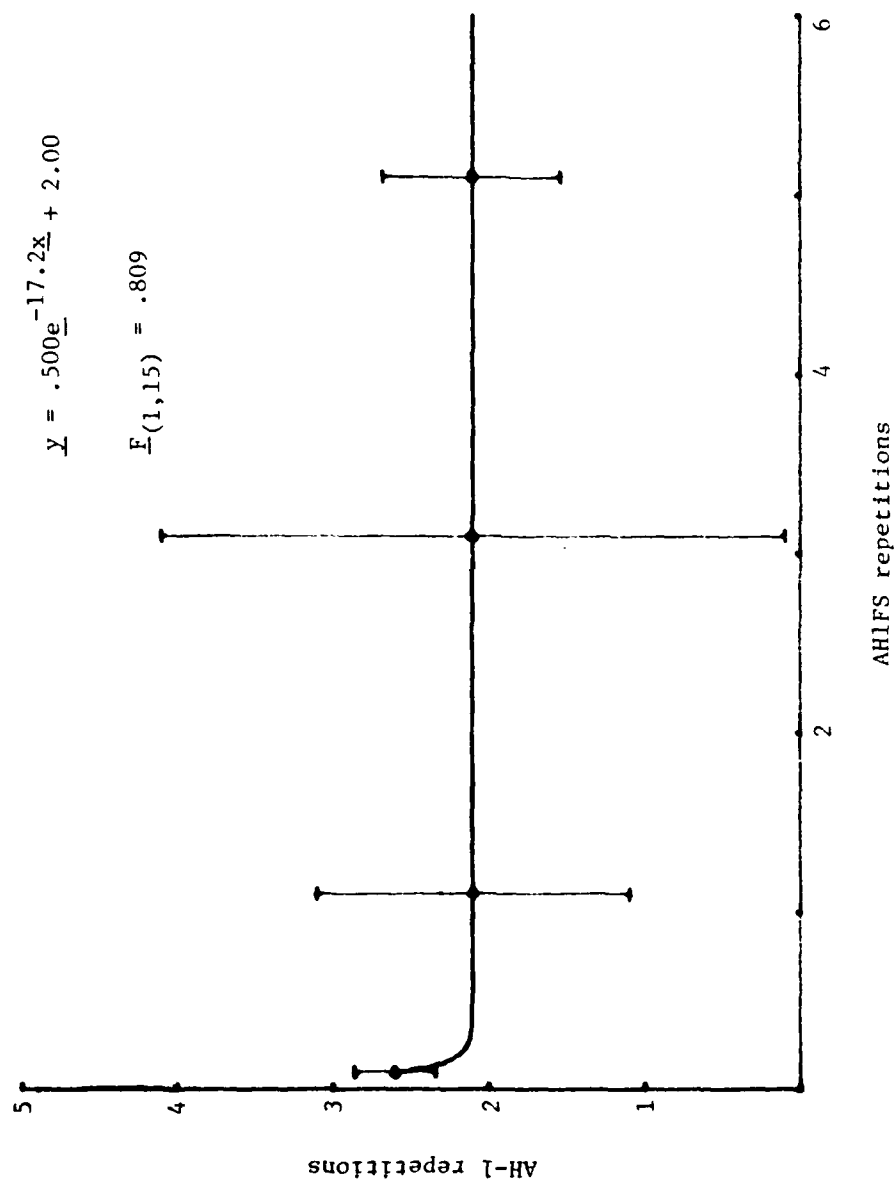
Figure 19. Autorotation, termination with power. (Axes offset to aid legibility.)

$$\underline{y} = .500\underline{e}^{-17.2\underline{x}} + 2.00$$

$$\underline{F}_{(1,15)} = .809$$

AH1FS repetitions

AH-1 repetitions

29

$$\underline{y} = 3.59\underline{e}^{-(1.7 \times 10^{54})\underline{x}} + 2.06$$

$$\underline{F}_{(1,28)} = 1.99$$

AH1FS repetitions

AH-1 repetitions
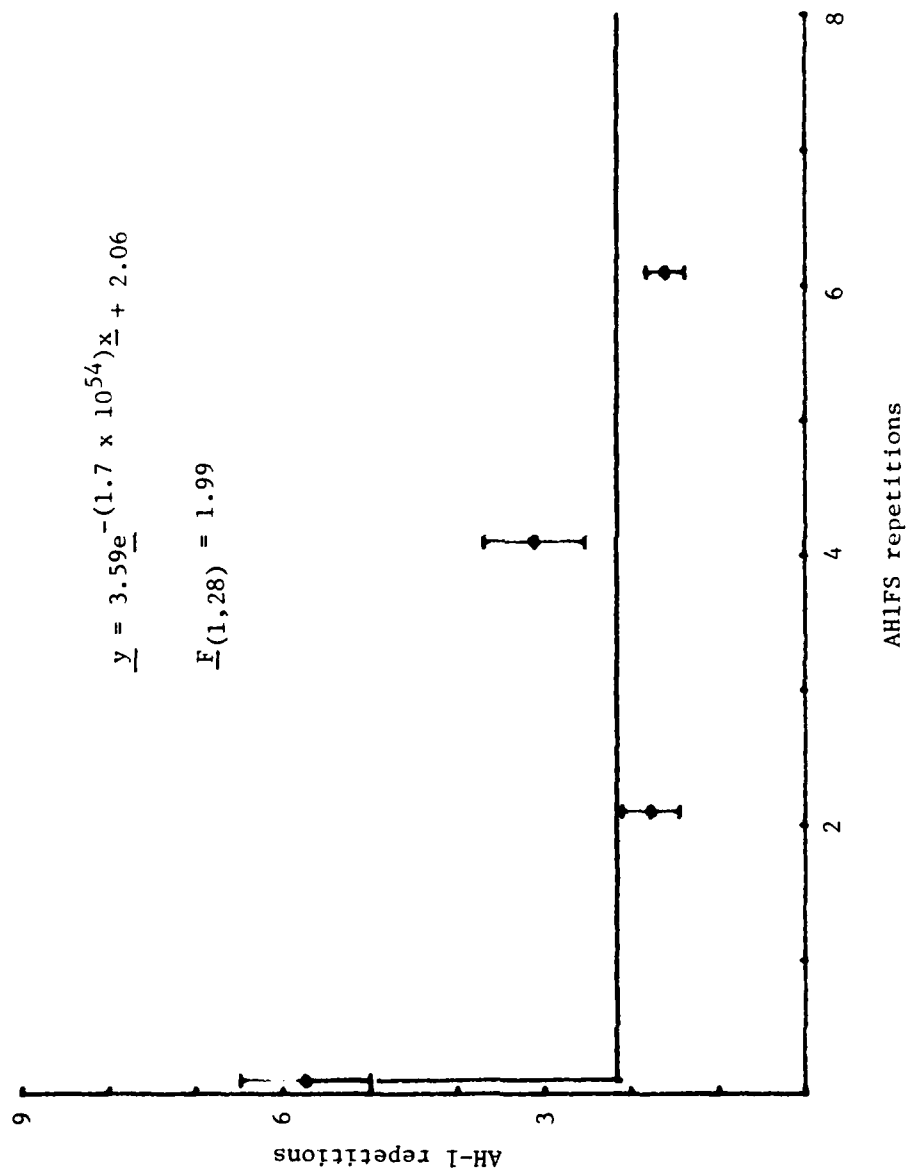
Figure 20. Hovering autorotation. (Axes offset to aid legibility.)

$$\underline{y} = 8.52e^{-.316\underline{x}} = 1.55$$

$$\underline{F}_{(1,24)} = .418$$
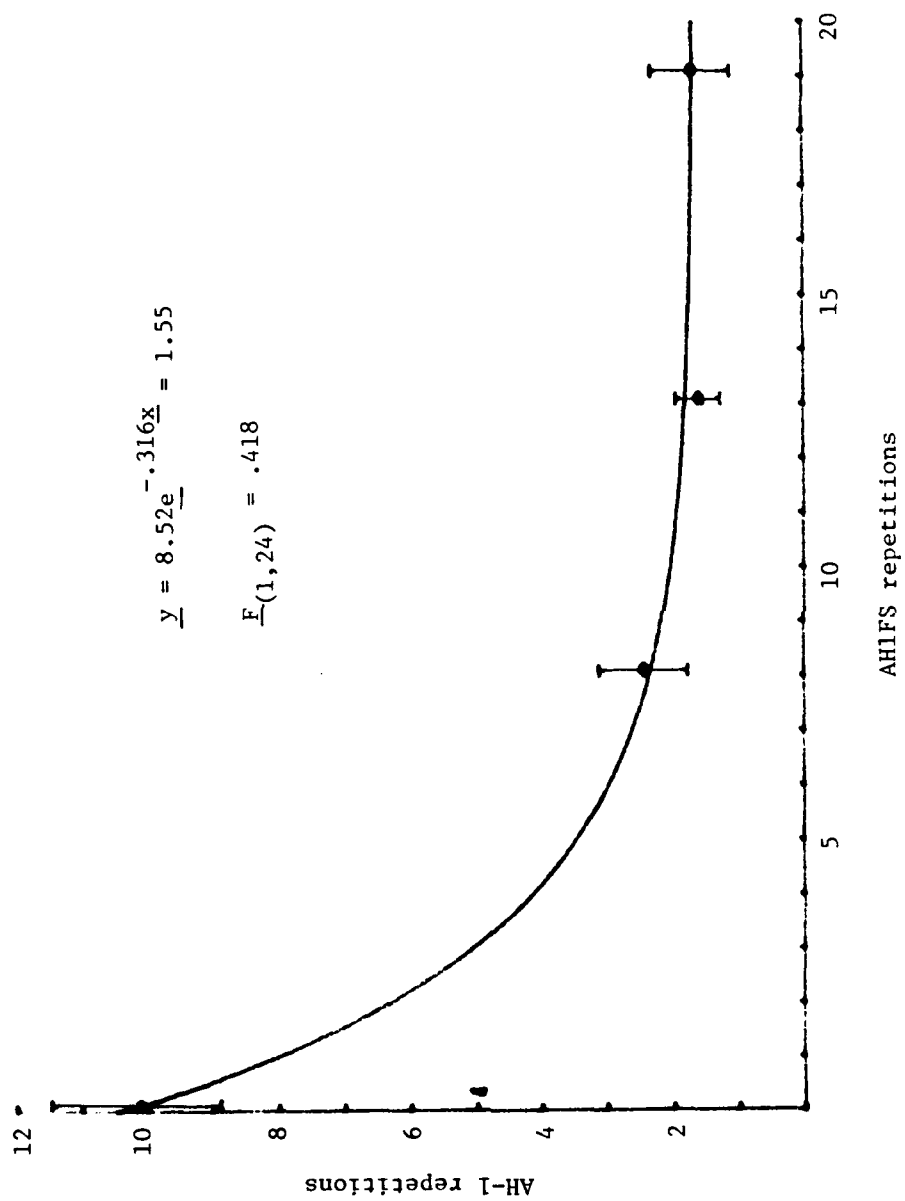
Figure 21. Left anti-torque failure.

31

$$\underline{y} = 6.99e^{-.548\underline{x}} + 1.51$$

$$\underline{F}_{(1,23)} = 1.56$$
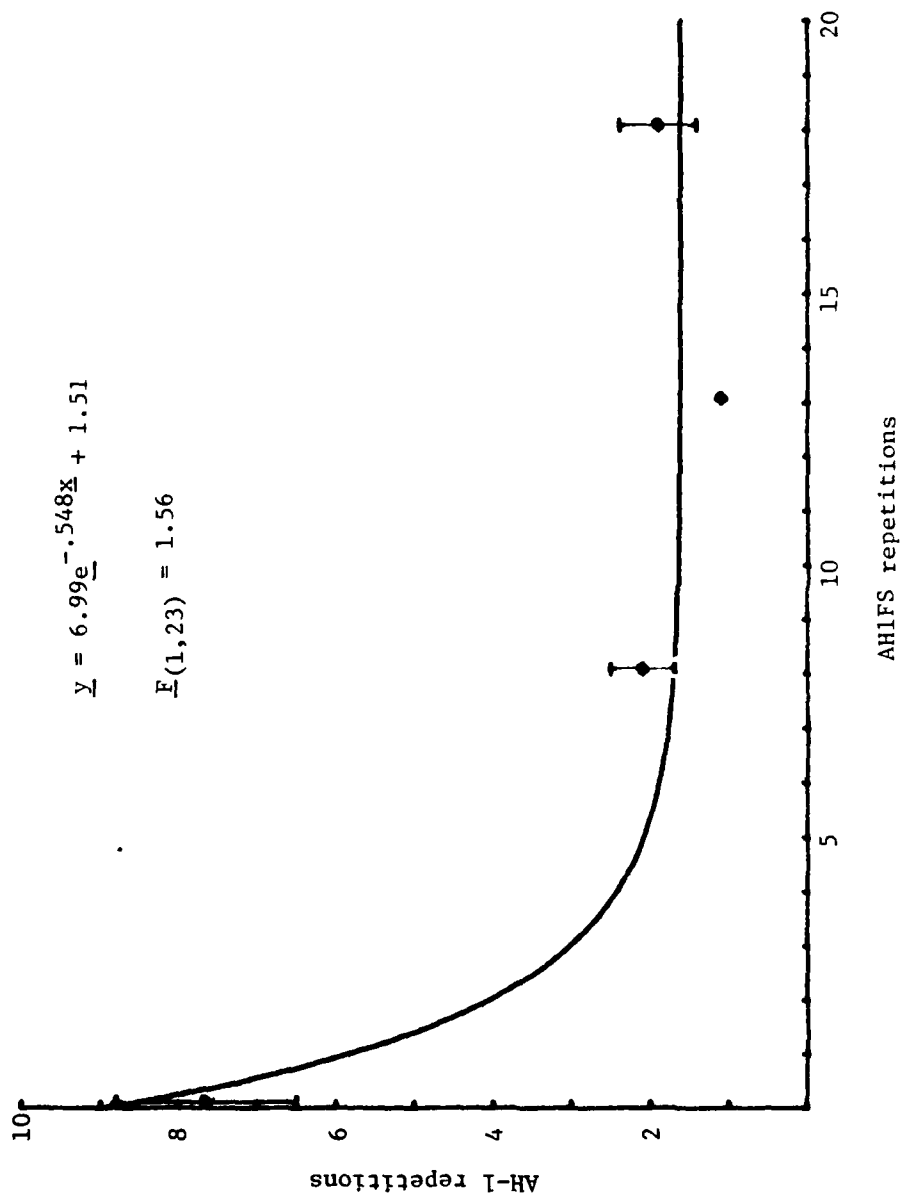
Figure 22. Right anti-torque failure.

32

$$\underline{y} = 3.57e^{-(2.5 \times 10^5)\underline{x}} + 3.2$$

$$\underline{F}(1,24) = .928$$
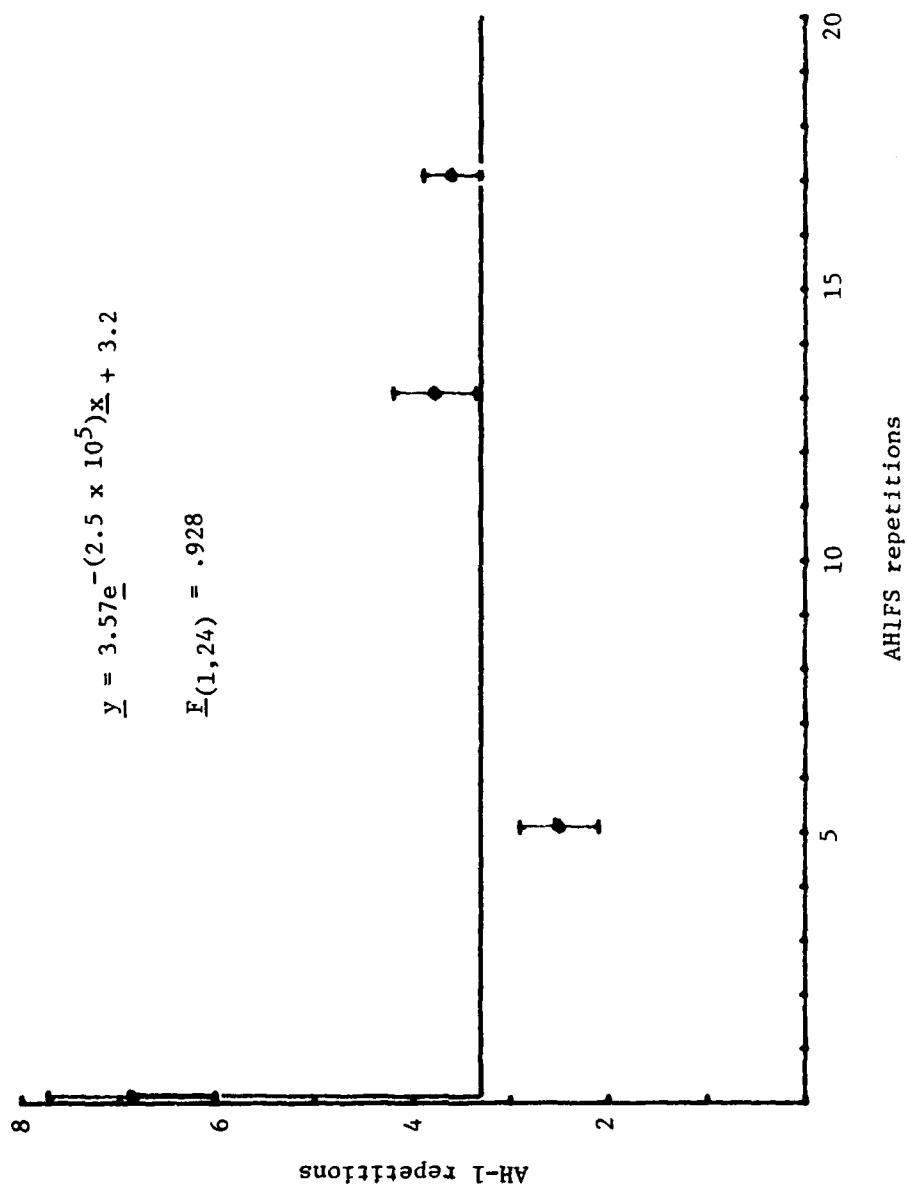
Figure 23. Low-level autorotation.

$$\underline{y} = 1.62\underline{e}^{-17430\underline{x}} + 2.54$$

$$\underline{F}_{(1,22)} = 1.33$$

AH1FS repetitions

AH-1 repetitions
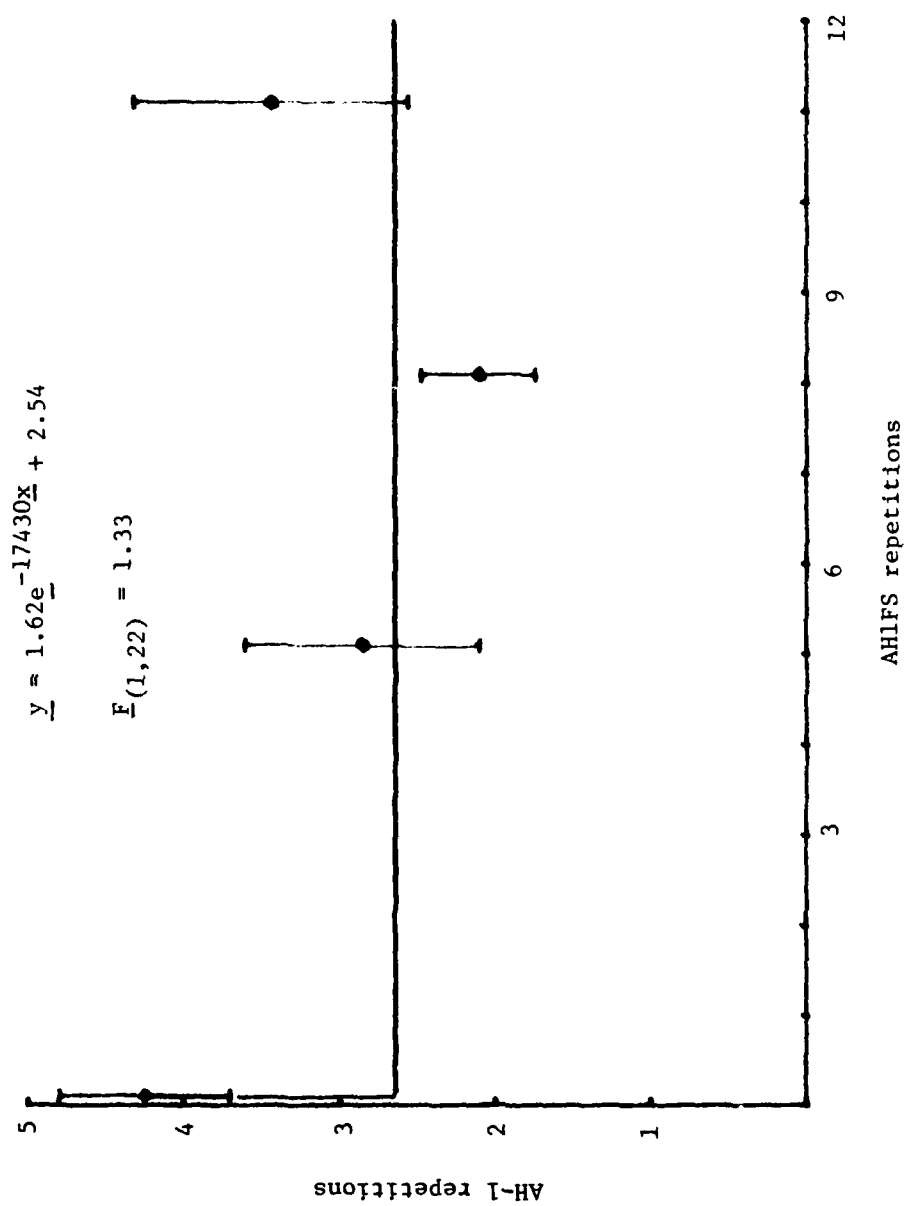
Figure 24. Low-level, high-speed autorotation.

34

$$\underline{y} = 1.89\underline{e}^{-2265\underline{x}} + 1.25$$

$$\underline{F}_{(1,21)} = 3.65$$
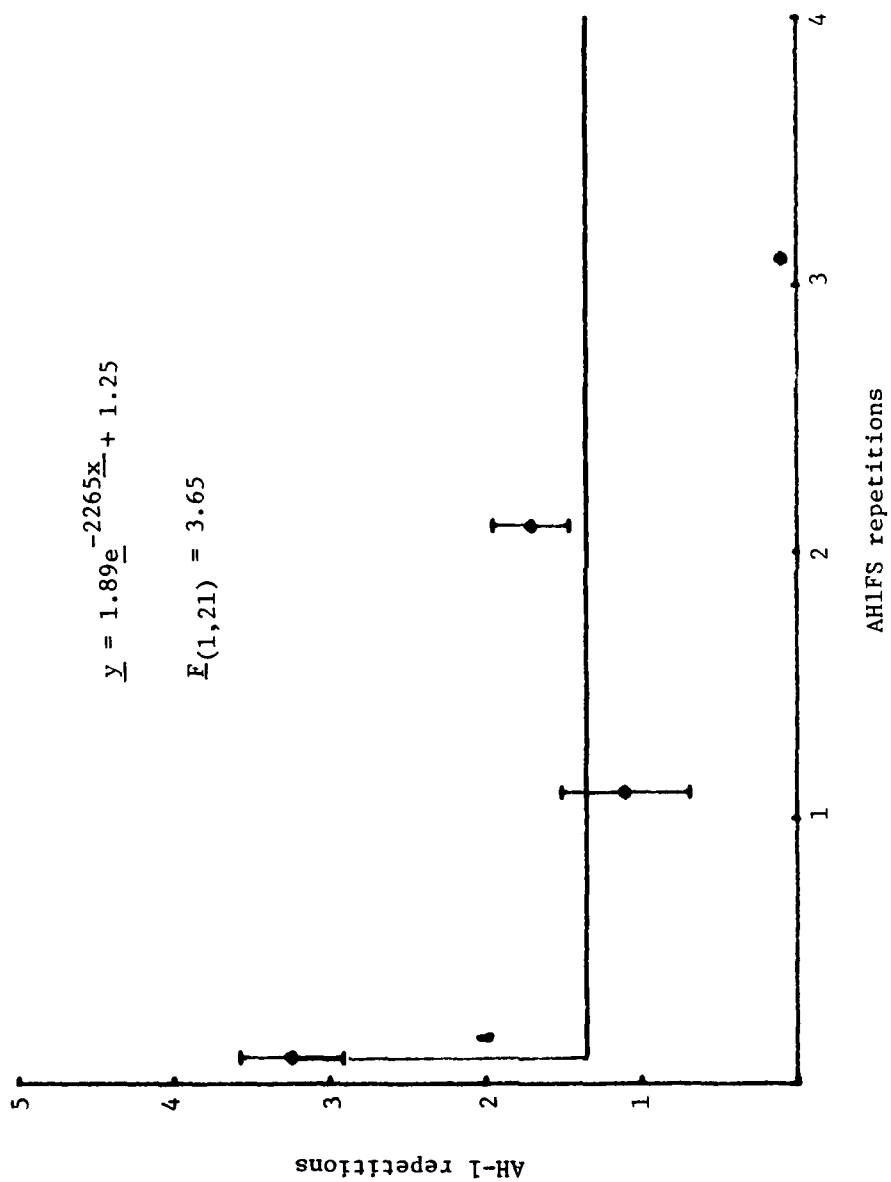
Figure 25. Hover out of ground effect. (Axes offset to aid legibility.)

35

$\underline{y} = 3.73\underline{e}^{-1.388\underline{x}} + .27$

$\underline{F}_{(1,19)} = .046$

AHlFS repetitions

AH-1 repetitions
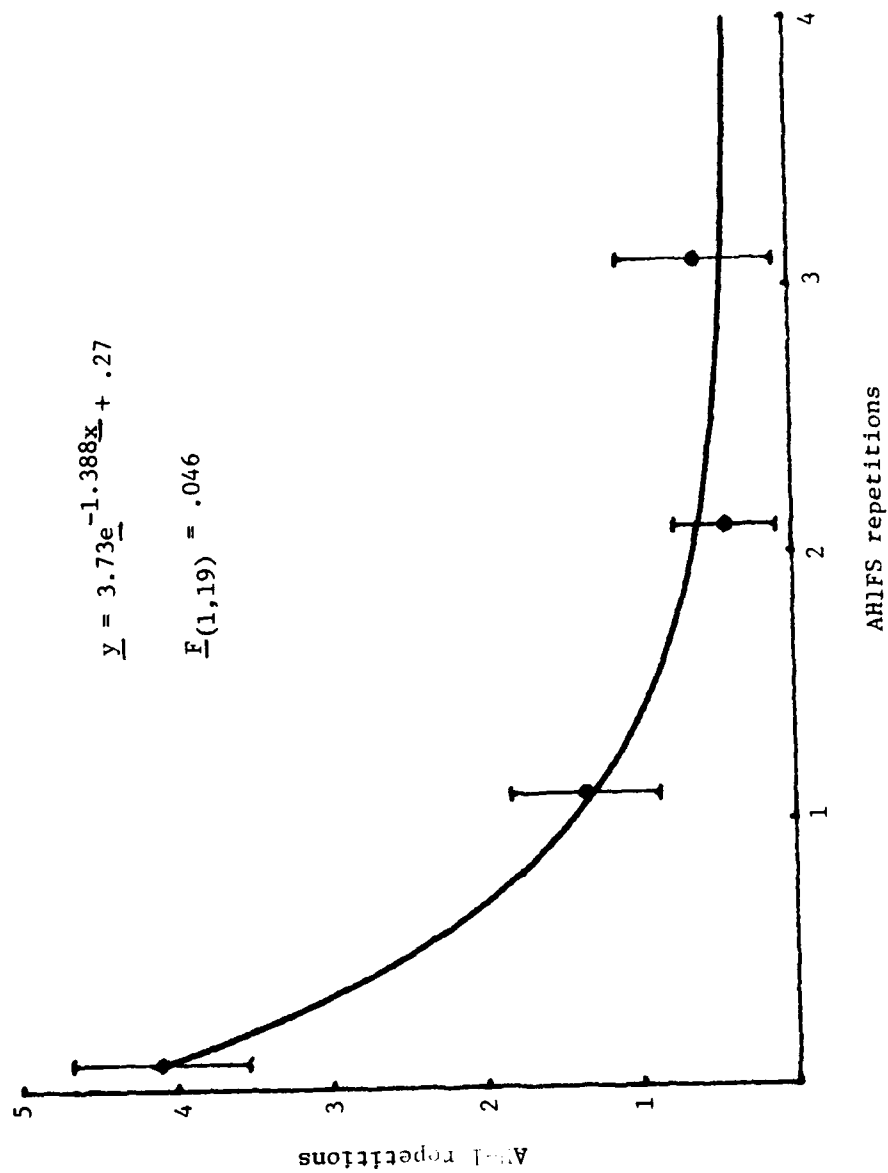
Figure 26. Terrain flight takeoff. (Axes offset to aid legibility.)

$$\underline{y} = 3.81\underline{e}^{-1.149\underline{x}} + .55$$

$$\underline{F}_{(1,2)} = .214$$

AH-1 repetitions

AH-1 repetitions
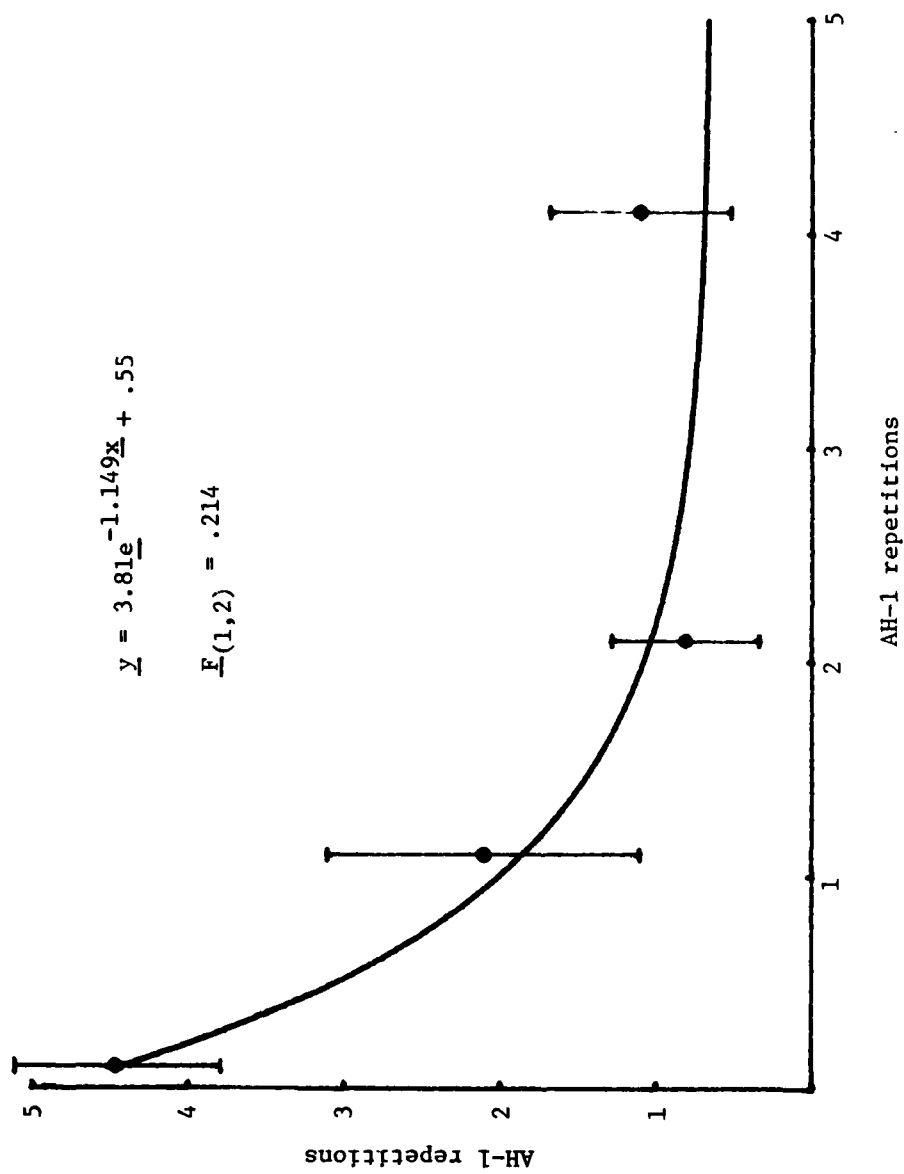
Figure 27. Terrain flight. (Axes offset to aid legibility.)

37

$$\underline{y} = 3.29e^{\frac{-17.16\underline{x}}{}} + 1.0$$

$$\underline{F}_{(1,18)} = .229$$

AH1FS repetitions

AH-1 repetitions
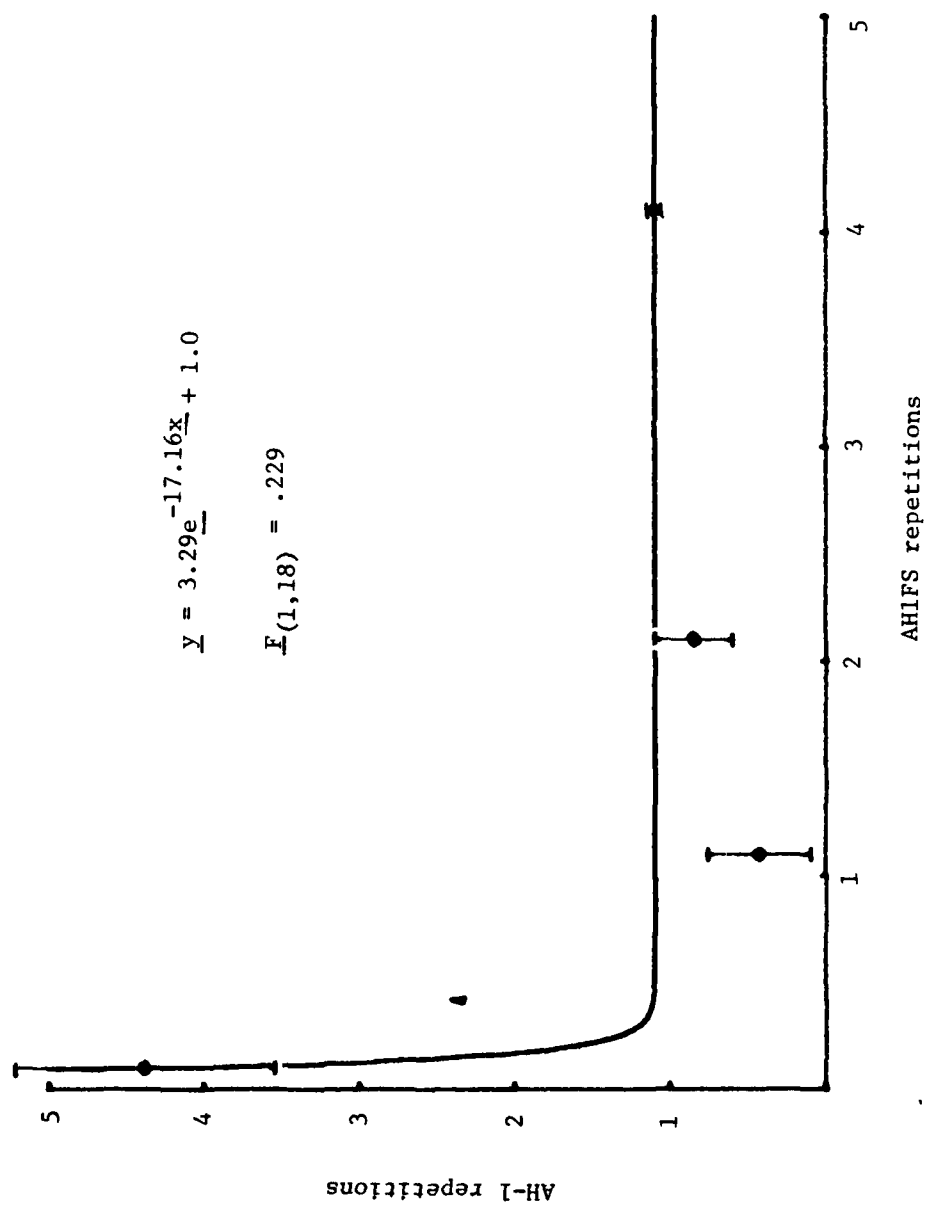
Figure 28. Terrain flight approach. (Axes offset to aid legibility.)

$$\underline{y} = .096\underline{e}^{-1.56\underline{x}} + 2.16$$

$$\underline{F}_{(1,18)} = 1.98$$

AH1FS repetitions

AH-1 repetitions
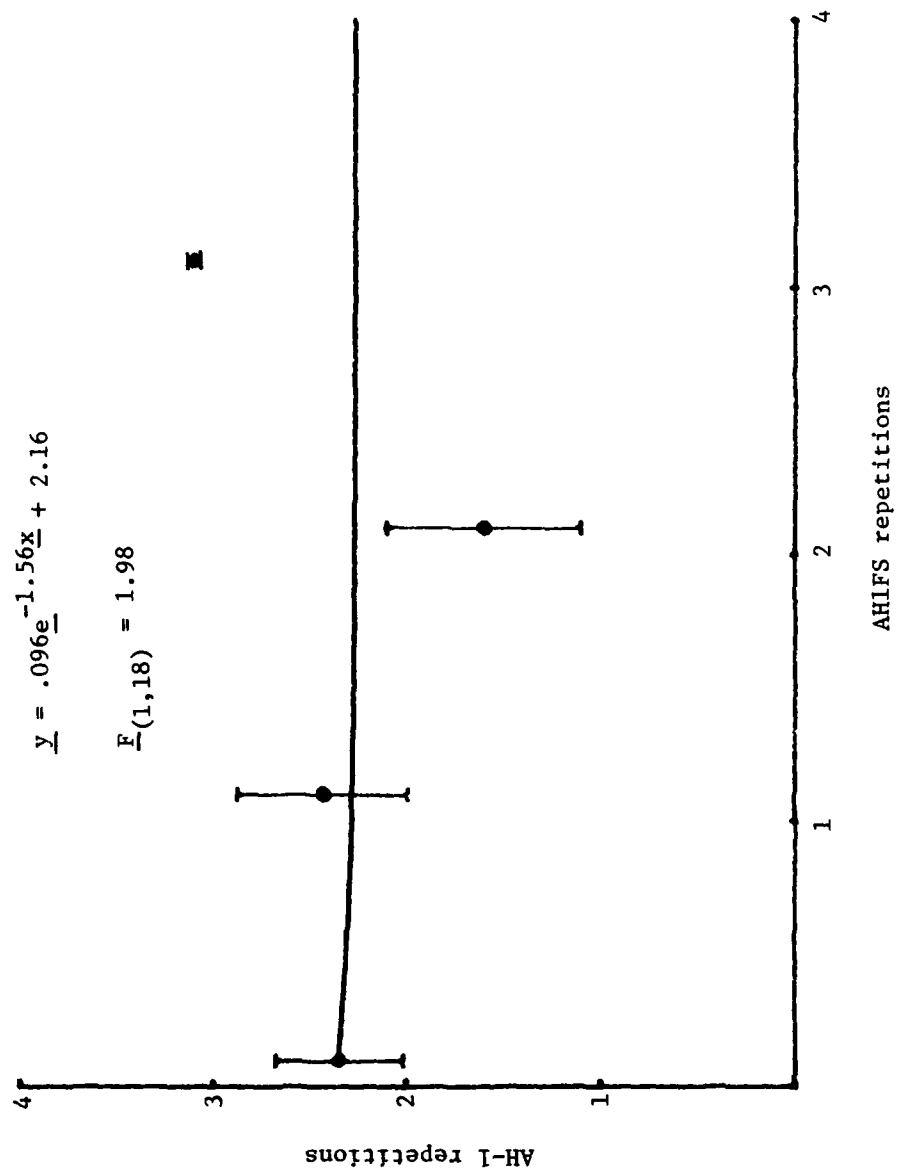
Figure 29. SCAS off operations. (Axes offset to aid legibility.)
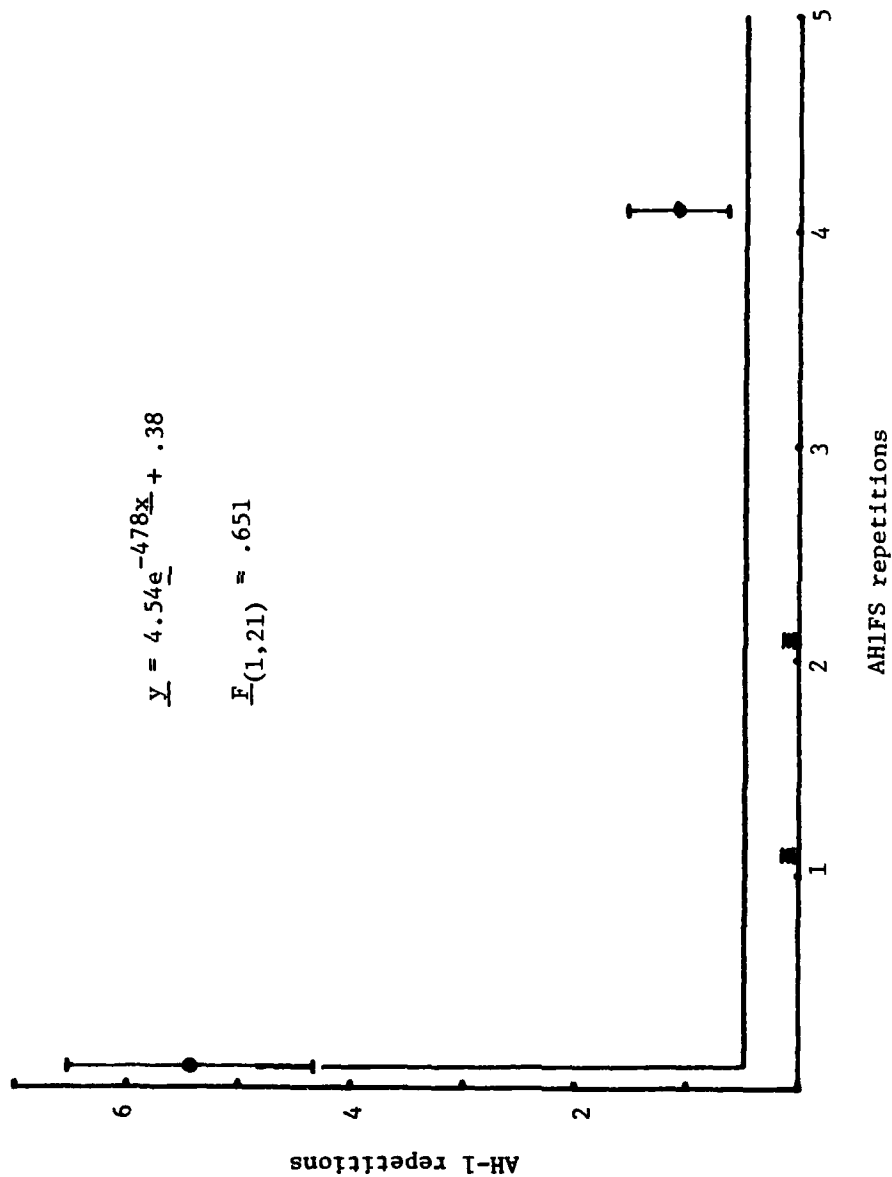
Figure 30. Weapons cockpit procedures. (Axes offset to aid legibility.)

$$\underline{y} = 4.54\underline{e}^{-478\underline{x}} + .38$$

$$\underline{F}_{(1,21)} = .651$$

40

$$\underline{Y} = 5.16\underline{e}^{-(5.2 \times 10^{13})\underline{x}} + .07$$

$$\underline{F}_{(1,23)} = .02$$

AH1FS repetitions

AH-1 repetitions
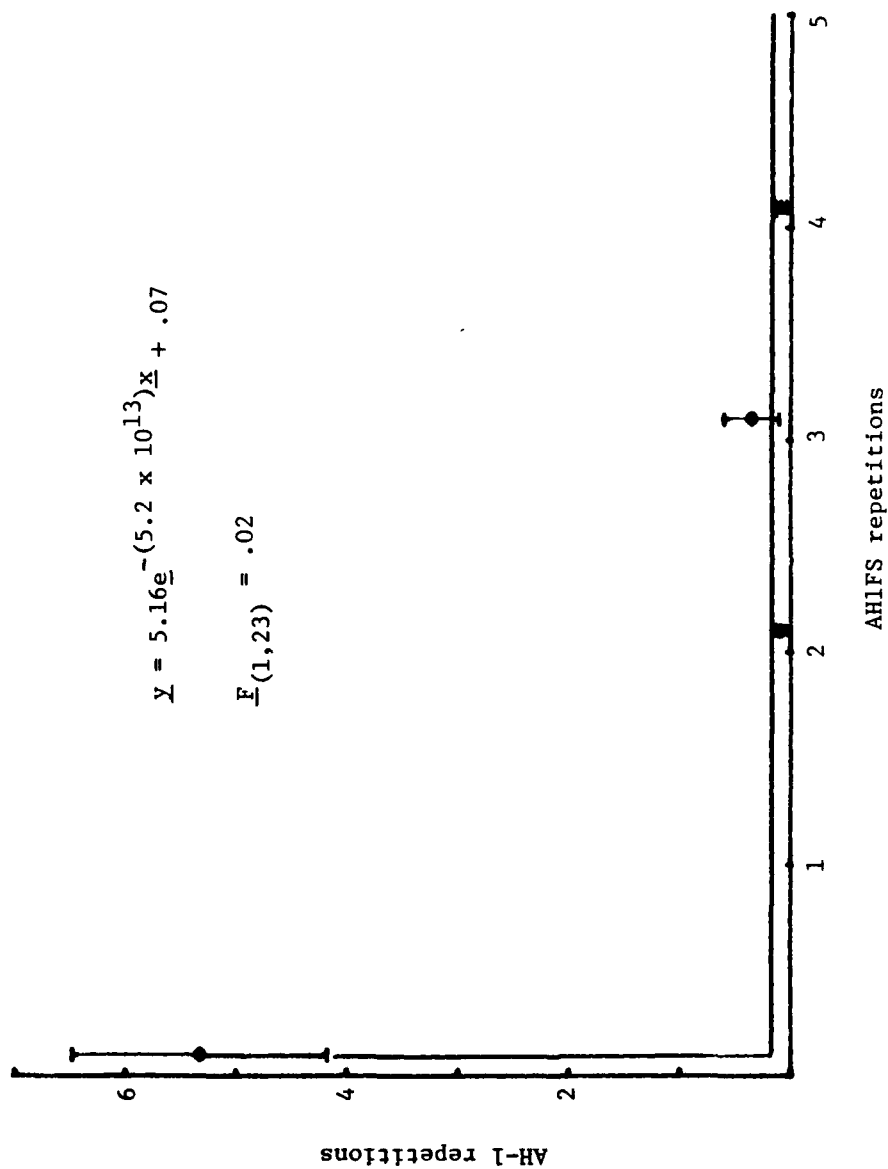
Figure 31. FFAR ballistic correction. (Axes offset to aid legibility.)
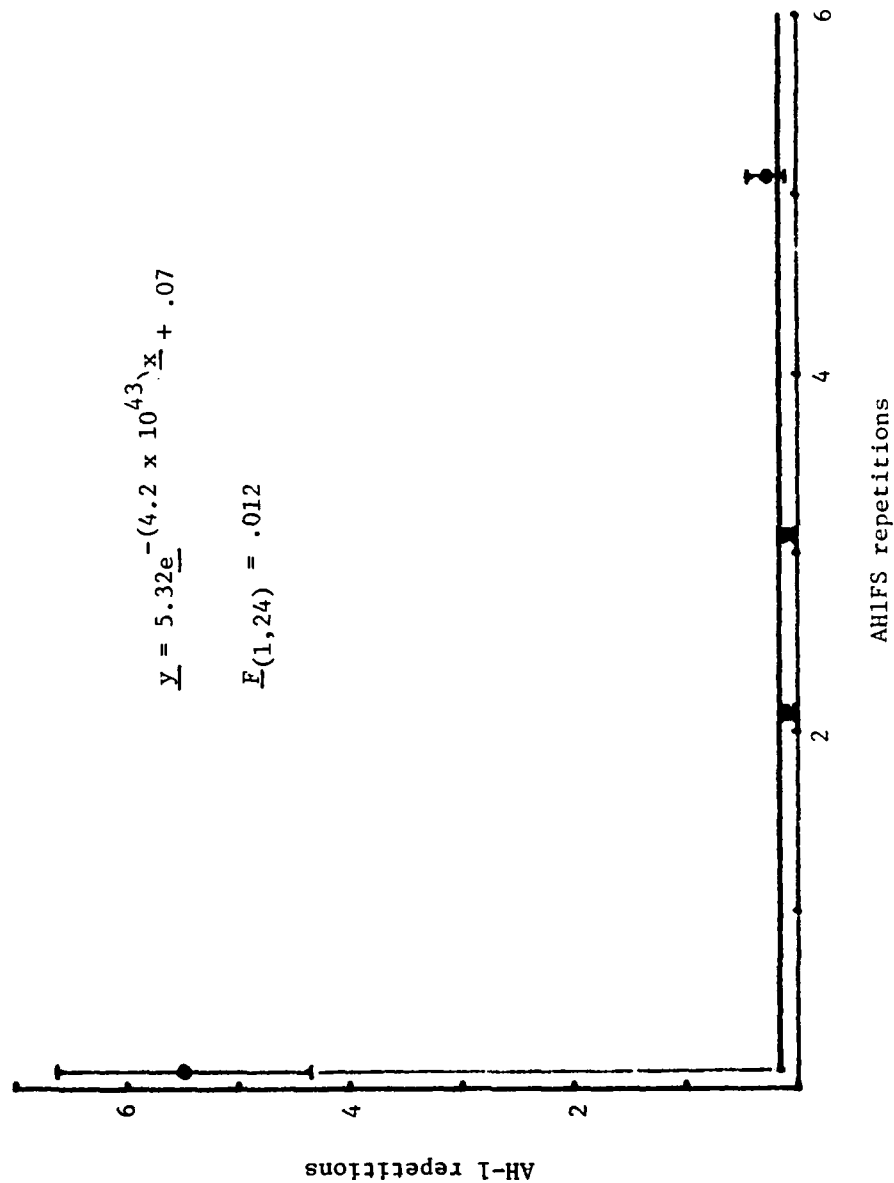
Figure 32. FFAR firing. (Axes offset to aid legibility.)

$$\underline{y} = 2.16\underline{e}^{-3180\underline{x}} + .07$$

$$\underline{F}_{(1,23)} = .147$$
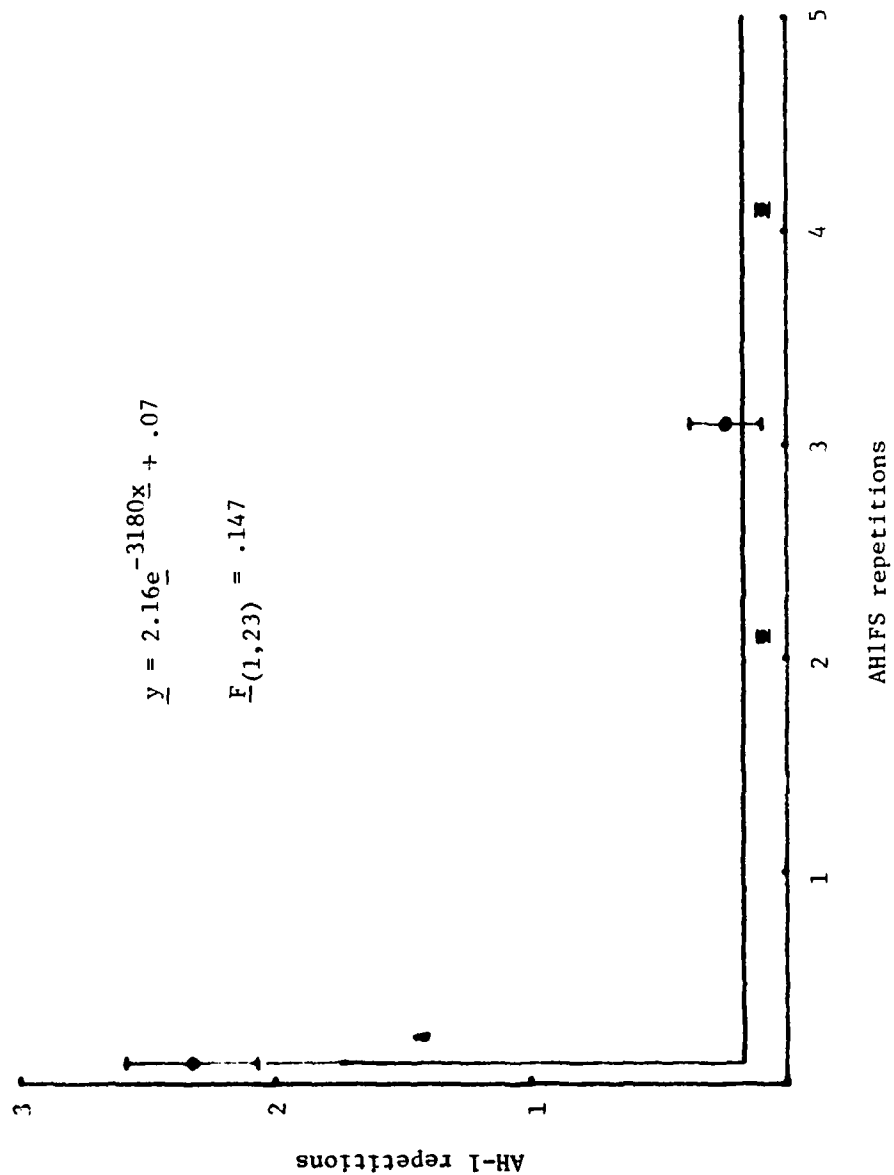
Figure 33. 20mm ballistic correction. (Axes offset to aid legibility.)

$$\underline{Y} = 2.38\underline{e}^{-(1.6 \times 10^{7})\underline{x}} + .08$$

$$\underline{F}_{(1,20)} = .102$$

AH1FS repetitions

AH-1 repetitions

Figure 34. 20mm firing. (Axes offset to aid legibility.)

44

As indicated at the outset, a major objective of the test of the AH1FS was to evaluate a methodology for quantifying training and cost effectiveness of simulators. In this section, the success of the methodology in capturing the simulator's effectiveness will be scrutinized, and a straightforward application of the results to curriculum development will be outlined.

Training Effectiveness

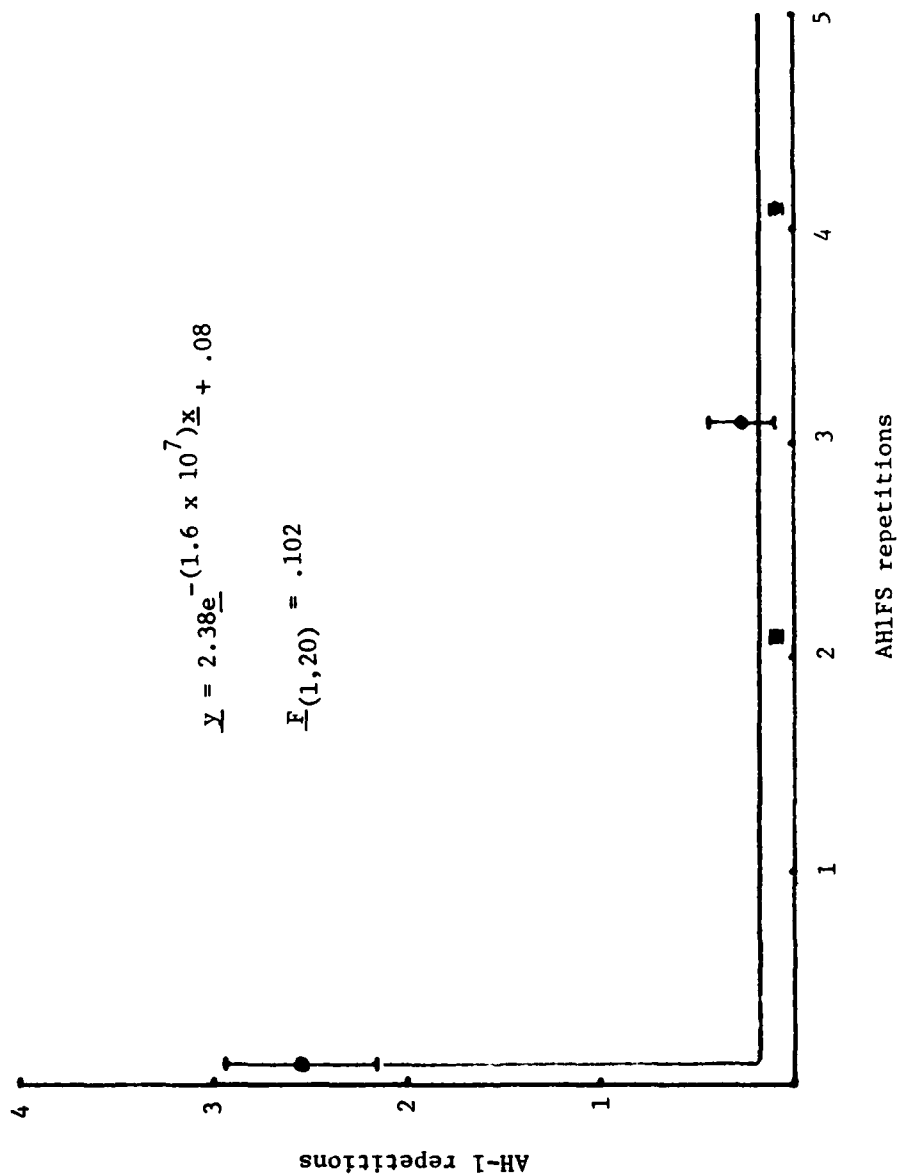The overall data indicate that the AH1FS is an effective device in training nearly all maneuvers investigated. This conclusion is evidenced by the general reduction in required aircraft training for each maneuver following simulator training. But results of particular interest are those pertaining to the accuracy of the transfer model and the success of the methodology in obtaining usable input for efficient curriculum design.

Presence of Trends. The initial data analysis indicates that in most cases there is a functional relationship between the amount of simulator training and the amount of subsequent aircraft training. Table 3 shows that for this sample, except for "autorotation, termination with power" and "SCAS off operations," between 25% and 80% of the variance in aircraft training amounts can be accounted for by the amount of simulator training, depending on the maneuver. Hence, there is some motivation for attempting to fit a model to the data.

Goodness-of-fit. In all cases, the model fits the data for each maneuver with values for $\underline{a}$ and $\underline{c}$ within their theoretically expected ranges. (Problems with values for $\underline{b}$ will be discussed below.) However, it is difficult to judge the absolute goodness-of-fit of any model. For the curve-fitting routine used with most, parameter values are selected that maximize the precision with which the dependent variable can be predicted from the independent variable. Of course, the predicted values and their corresponding observed dependent variable values will differ; the magnitude of the variance of this difference is a general indicant of goodness-of-fit: small variance results from a good fit. However, for a given level of the independent variable, there will be variance in the resultant levels of dependent variable observed. If this variance is conceptualized as the "noise" inherent in the data, then at least that much noise is also to be expected in the precision of prediction using the best-fit parameters. To the extent the variance of the fit's precision exceeds that of the dependent variable observed values, the fit can be regarded as bad. Conversely, a good fit will yield a precision variance not significantly larger than the dependent variable variance. The $\underline{F}$-ratios in Figures 4 through 34 (Lewis, 1960) compare these variances; none is significant at the $\underline{\alpha} = .05$ level. But this is somewhat to be expected because the experimental design could economically allow sampling at only four values of the independent value, and the model is left to fit the four resulting mean dependent variable values with three free parameters. A "good" fit is not necessarily "the" fit; there are other models and theoretical functions that would fit the data just as well or even better. For example, Cronholm (1980) has pointed out that if both simulator and aircraft learning curves are assumed exponential with rate parameters $\underline{g}$ and $\underline{h}$, respectively, then a good case can be made for a function of the form $\underline{y} = (\underline{h}^{-1})\ln(\underline{ae}^{-\underline{gx}} + \underline{c})$.

Thus it may only be concluded that there is no cogent reason for rejecting as a viable heuristic the model under consideration.

Selection of Independent Variable Levels. As mentioned previously, experimental values of the independent variable ideally should be chosen so that not all three yield dependent variable values falling in the asymptotic portion of the curve. Despite the attempts made to avoid them, such choices were apparently made in the cases of several maneuvers.

For example, consider "takeoff to a hover" shown in Figure 5. Based on various considerations, it was decided to sample the independent variable at levels of zero, 13, 19, and 24 repetitions. Inspection of Figure 5's best-fit curve indicates that 13 or more AH1FS training repetitions yield results in the asymptotic area of the function. The reiterative curve-fitting routine used, in effect, fit these asymptotic data with a line parallel to the abscissa.[1] Although it may be that one training repetition in the AH1FS is effective to the extent indicated by the curve, it is much more likely that if an independent variable value in the range of three to seven repetitions had been chosen, a much less acute function would have been obtained.

A somewhat different situation seems to have arisen in Figures 25 and 30 through 34. Figure 25 indicates one repetition in the AH1FS to be effective in training "hover out of ground effect," a fairly simple maneuver, but that almost no additional effectiveness accrues from additional repetitions. Similarly, it appears that the gunnery maneuvers in Figures 30 through 34 transfer almost immediately and completely from the AH1FS to the AH-1 aircraft.

Integration of Cost with Training Effectiveness

Since costing procedures for both the simulator and the aircraft use hours of operation rather than numbers of maneuver repetitions, the training analyst should determine the average time required per maneuver in each training device prior to integrating cost and training effectiveness. Then the appropriate transformations of axes of curves such as those in Figures 4 through 34 can be made so that the abscissae's unit of measure is units of simulator time and the ordinates' unit of measure is units of aircraft time.

Device Operation Costs. To determine economically optimal mixes of simulator and aircraft time, the training analyst must be provided the cost per unit of operating time for both devices. If this figure for the simulator is designated C_S, then the function describing the total cost of x units of simulator training time will be the product $C_S x$ as shown in Figure 35a. Likewise, if after x units of simulator training, y units of aircraft training are required, the total cost of this training will be the product $C_A y$, where C_A is the cost per unit of aircraft training time. Since it has been shown that the y units of required aircraft training time can be expressed as a function of x as $ae^{-bx} + c$, then the cost of required aircraft training can be more explicitly expressed as $C_A(ae^{-bx} + c)$ as in Figure 35b. Then, for any one maneuver, the total cost can be expressed as
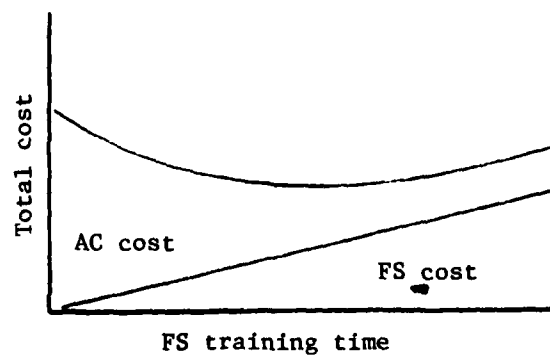
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[1] Note that for moderately large values of b, the value of ae^{-bx} quickly approaches zero.
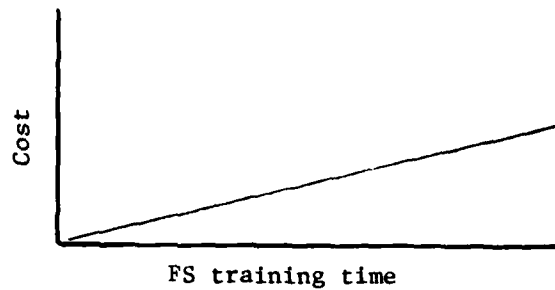
a. Cumulative FS training cost as a function of FS training time.
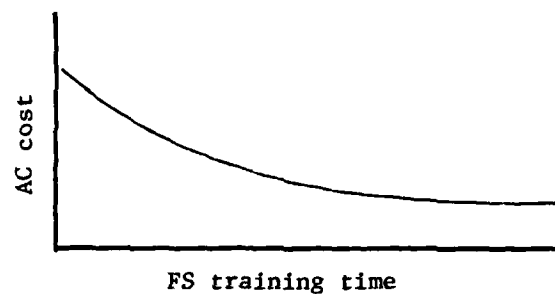
b. Cumulative aircraft training cost as a function of FS training time.

c. Cumulative total cost as a function of FS training time.

Figure 35. Integration of simulator and aircraft training costs.

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$$\underline{C} = \underline{C}_S \underline{x} + \underline{C}_A (\underline{a}\underline{e}^{-bx} + \underline{c}), \tag{6}$$

which is shown in Figure 35c.

Inspection of Figure 35c indicates a point at which total cost is minimized, and it can be shown mathematically[2] that equation 6 is at a minimum when

$$\underline{x} = (\ln\underline{C}_A + \ln \underline{a} + \ln \underline{B} - \ln \underline{C}_S) (\underline{b}^{-1}). \tag{7}$$

If for any maneuver $\underline{m}$ this optimal value of $\underline{x}$ is denoted as $\underline{x}'_m$, then total optimized training cost for all $\underline{M}$ maneuvers can be expressed as

$$\underline{C}'_T = \sum_{m=1}^{M} \underline{C}_S \underline{x}'_m + \underline{C}_A (\underline{a}_m \underline{e}^{-b_m x'_m} + \underline{c}_m) \tag{8}$$

and the raw savings realized will be, of course, the difference between $\underline{C}_T$ evaluated at $\underline{x} = 0$ and $\underline{C}'_T$ of equation 8. Thus the model and methodology presented here are both viable and of great utility to the training analyst.

Further Considerations

Although the methodology presented here is fairly straightforward, there are some additional factors to be kept in mind about applying its results in developing a simulator-based training system.

Effects of Curriculum. It is an inescapable fact that regardless of the level of technology and the sophistication of a simulator, its effectiveness is a function of how it is used--of how the trainer incorporates its features into a training program. The quantitative measures of effectiveness determined by this study are very much a function of how the IPs used the simulator as a training device. Also, even though each maneuver is treated as an independent entity by the methodology, there are effects of training sequences. For example, antecedent simulator training on "normal approach" presumably has some positive transfer to subsequent simulator training on "terrain flight approach." Thus, as the simulator instructional tactics are refined, the AH1FS's effectiveness should improve. Consider in this light, the trade-off curves determined by the study represent not the optimum effectiveness of the device, but the baseline effectiveness.

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[2] $\dfrac{d\underline{C}}{d\underline{x}} = \underline{C}_S - \underline{C}_A\underline{abe}^{-bx}$, which, when set at zero and solved for $\underline{x}$, yields equation 7.

$\dfrac{d^2\underline{C}}{d\underline{x}^2} > 0$ (given $\underline{a} > 0$ and $\underline{b} > 0$) implies that $\underline{x}$ in equation 7 represents a minimum.

Restricted Device Availability. Most modern simulators are expensive and must be distributed among a large number of trainees. In all cases, the training analyst will have the device available for a certain period each day. In many cases the analyst is also faced with cycling through the curriculum a large number of students within a fixed number of training days. These restrictions determine the amount of simulator time available to each student. Ideally, the amount of time per student would be at least equal to the total optimal maneuver training times. In many instances, this is not the case, and less than optimal training curricula must be set up according to some trade-off scheme.

In his implementation of the integration procedures outlined here, Hopkins (1980) ordered the simulator-trainable maneuvers in terms of each maneuver's savings per hour of simulator operation. (In general, more savings per unit of simulator operating time accrue to maneuvers for which the difference $\underline{a} - \underline{c}$ is great and the rate parameter $\underline{b}$ is large.) Choosing a hypothetical 3½ hour availability per student, he simply cumulated the $\underline{x}'$ values (in terms of time) down the rank-ordered list of maneuvers until they totaled 3½ hours. Other trade-off schemes might involve such considerations as weighting each maneuver according to the danger associated with performing it in the aircraft.

Conclusions

At the practical level, the model and methodology have been demonstrated as both viable and of utility. The model does not concern itself directly with such issues as fidelity and realism, but addresses directly the effectiveness of the simulator in decreasing required aircraft training time. As expressed in equation 5, the model considers only antecedent simulator training as a predictor variable. Other variables, such as student experience level, student aptitude, or cumulative negative effects of simulator training can be incorporated into the model. However, the cost of empirically evaluating such an expanded model will increase in terms of levels of independent variables sampled and number of experimental subjects required.

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